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HOW IT WORKS Annual

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SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

WELCOME TO

HOW IT WORKS Annual

Welcome to the latest volume of the How It Works Annual, where your burning questions about how the world ticks finally get answered. Feed your mind, indulge your curiosity and uncover the truth behind some of the most popular misconceptions. We delve deep into the mysteries of our world with in-depth and entertaining articles, accompanied by cutaways, illustrations and incredible images to show you exactly what goes on inside. We've even brought some of our illustrations to life – just grab your phone and get exploring!

The How It Works Annual delves into the universe through six areas of knowledge: technology, transport, the environment, history, science and space. From microscopic body bugs to colonising the Solar System, you'll discover some of the most remarkable feats of the modern world! In this edition, we'll also find out if you've got what it takes to become a rally driver, why the unsinkable Titanic sank, and so much more. So are you ready to learn more about the astounding world around you?

Then read on and be amazed!

HOW IT WORKS Annual

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Printed by William Gibbons, 26 Planetary Road, Willenhall, West Midlands, WV13 3XT

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU
www.marketforce.co.uk Tel: 0203 787 9001

How it Works Annual Volume 11 (ANB 3253)

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Future plc is a public company quoted on the London Stock Exchange (symbol: FUTR)
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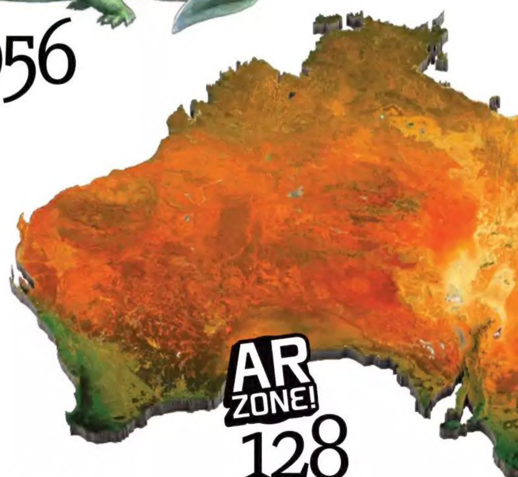

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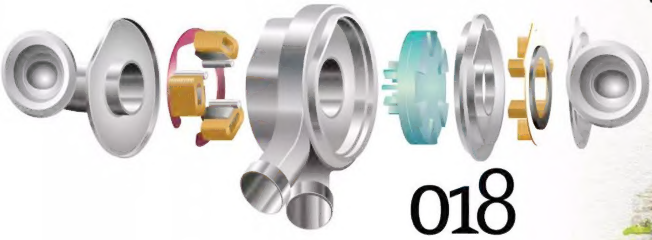

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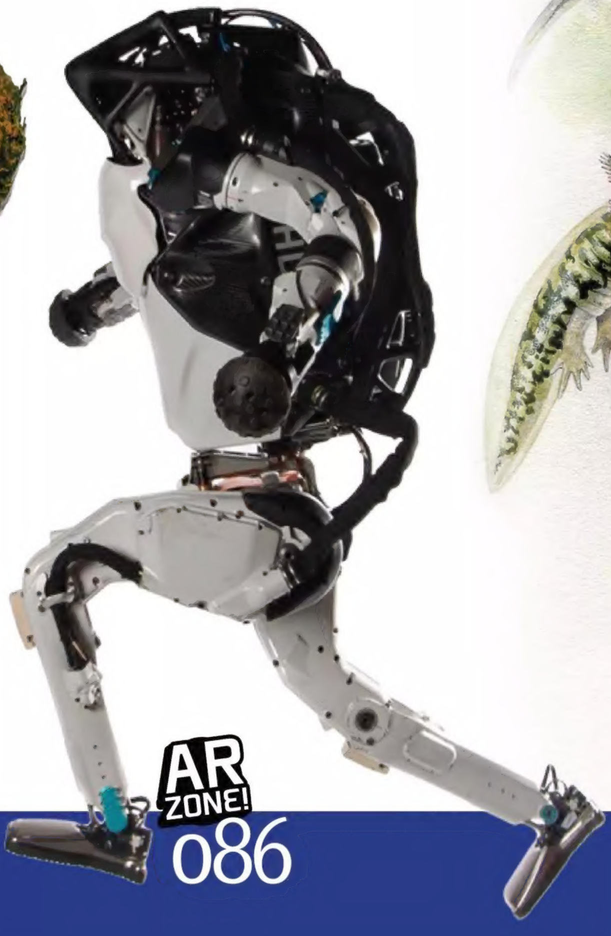

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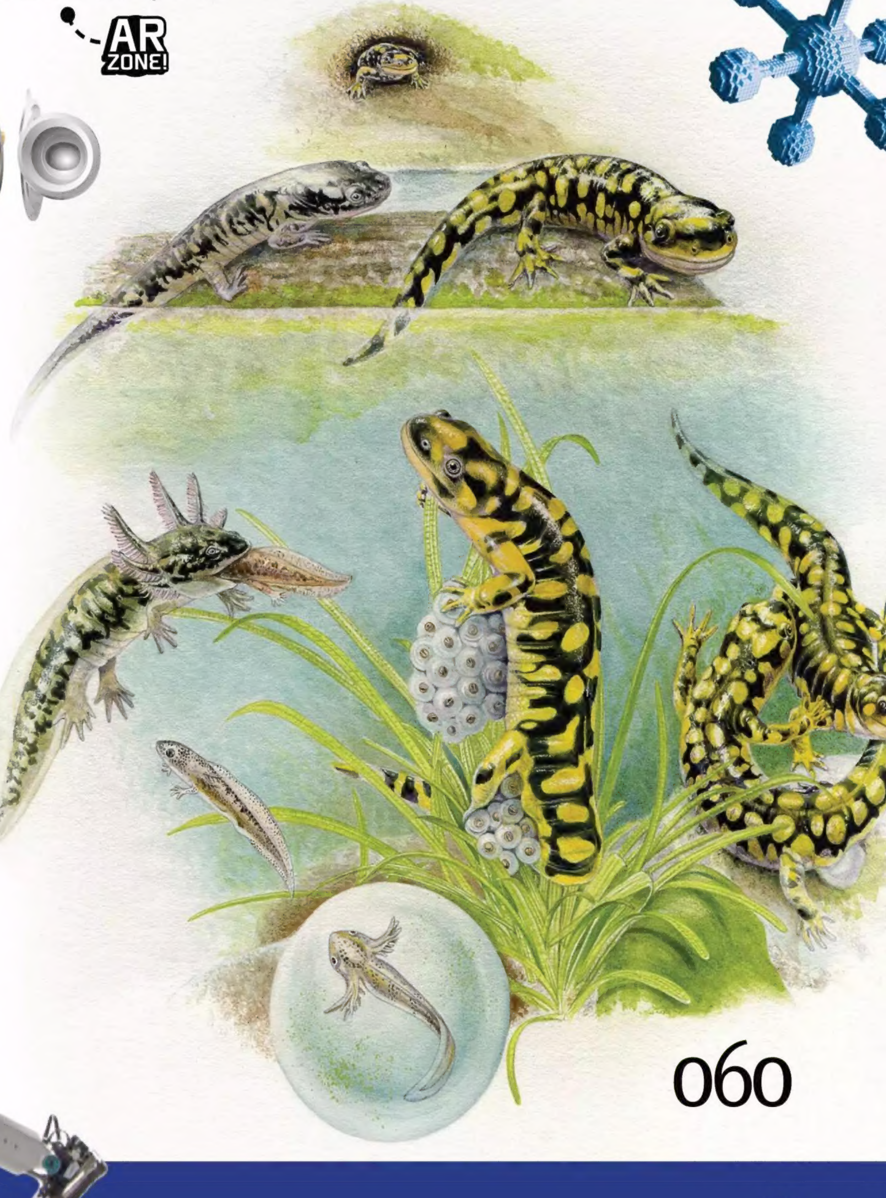

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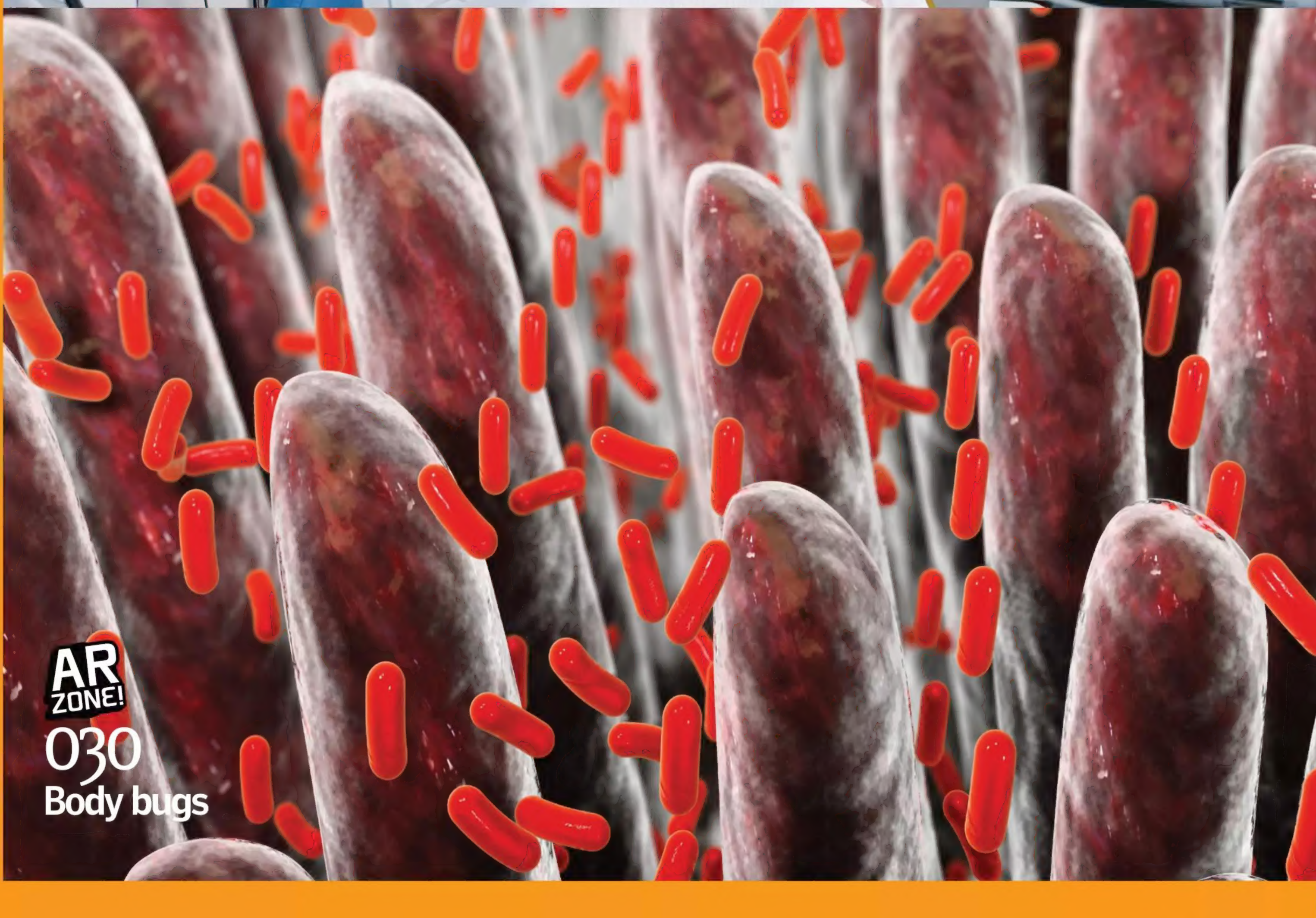
Inside intensive care



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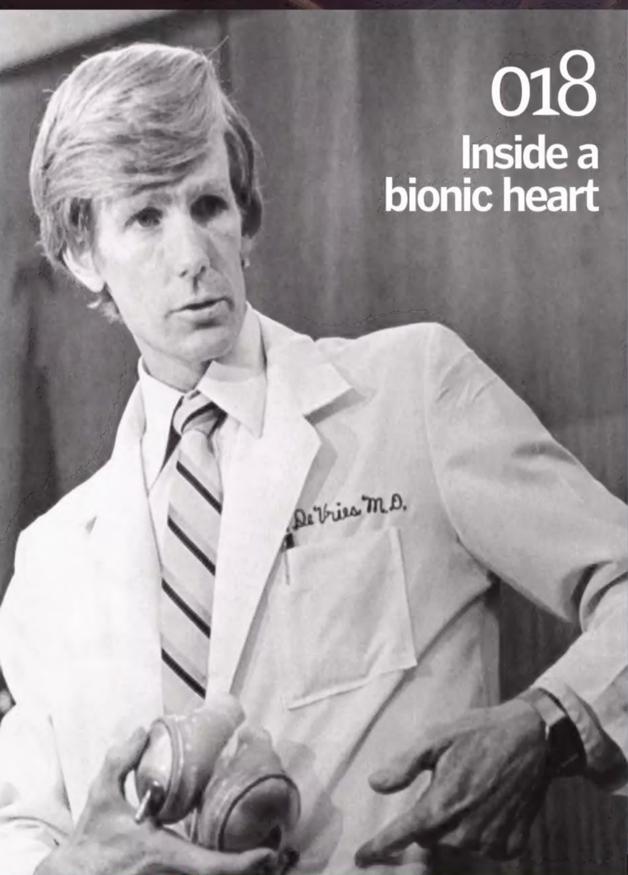


DeVries M.D.

INSIDE INTENSIVE

WHEN THE LINE BETWEEN LIFE AND DEATH BECOMES DANGEROUSLY FINE, HOW DO THE PEOPLE AND MACHINES IN HOSPITALS AID YOUR BODY'S BATTLE?

Words by **Ailsa Harvey**

DID YOU KNOW? *The first intensive care unit in the world was established in 1953 in Copenhagen*

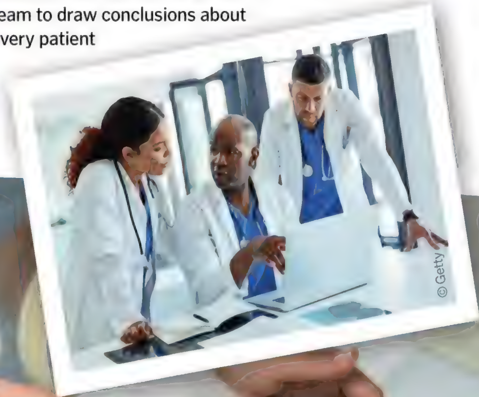
How long would we last without healthcare? What would we do without a number to call when we are reminded how fragile life can be, or a place to go with the confidence that we will receive the best possible care from a team of professionals who know our bodies inside out? While every area of a hospital has the improvement of health at its core, there is one department that elevates the emotion, urgency and stakes of every action to a much greater level. This is the intensive care unit (ICU).

Intensive care units, otherwise known as critical care units, are special wards within hospitals where patients with life-threatening conditions can be monitored and treated. People who qualify for ICU admittance are those whose conditions are unstable. They need to be monitored constantly to ensure that any changes are noticed and acted upon before irreversible damage is done.

It's a place nobody outside of the medical profession wishes to find themselves. Whether you are the patient yourself, relying on the tubes and machines that are taking on the role of your organs, or a visitor who can only sit at a bedside and hope that your loved one will pull through, the ICU is an undoubtedly gruelling environment. To an onlooker, the turn of every corner can overload the senses. The chaotic combination of mechanical beeps, frantic alarms and intense bedside operations are in stark contrast to the people lying still on their beds in occasional periods of eerie silence. Who knows what the next few seconds will bring?

For the various patients occupying these high-priority beds, the cause of their admission

Consultant doctors work with their team to draw conclusions about every patient



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Ten per cent of babies are born prematurely

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AR ZONE!

BEDSIDE TECH

When organs fail to stabilise life, patients are wired up to these computers to assist with bodily functions

Electrodes
For the EEG monitor to work, it needs to be connected to the brain. The best way to do this is through electrodes. Metal discs with multiple thin wires are attached to the scalp. The wires pick up any electrical activity in the brain and the information is transferred to the monitor.

Bedside monitor
Displaying some of the body's vital functions, such as heart rate, blood pressure, temperature and oxygen levels, this screen is connected to multiple devices. Equipped with alarms, if any function reaches dangerous levels, medical staff are instantly alerted.

Ventilator
This breathing machine helps the lungs to inhale and exhale air. A tight mask can be fitted to cover the mouth and nose. In more severe cases the patient needs to be sedated to insert the tube into their windpipe through their neck.

Central line
A thin, soft plastic tube called a catheter is inserted into a large vein. This entry to the bloodstream can be used to apply a dose of medicine or draw blood for testing.

1:2
On average, there is one nurse for every two level 2 patients in an ICU.

Electroencephalogram (EEG)
Recording electrical activity in the brain, this machine can visually display changes in brain function. Unusual recordings can help pinpoint causes of seizures or memory loss.

Dialysis machine
In cases of kidney failure, a machine can be attached to a large vein, often in the neck. Blood leaves the body through a tube and into the machine, which acts as a filter to remove harmful waste products from the blood. The filtered blood is then returned into the patient's body.

Pulse oximeter
To measure oxygen levels in the blood, this tool clips onto the end of the patient's finger. As wavelengths of light are passed through the finger, the device displays the body's pulse rate as well as oxygen levels.

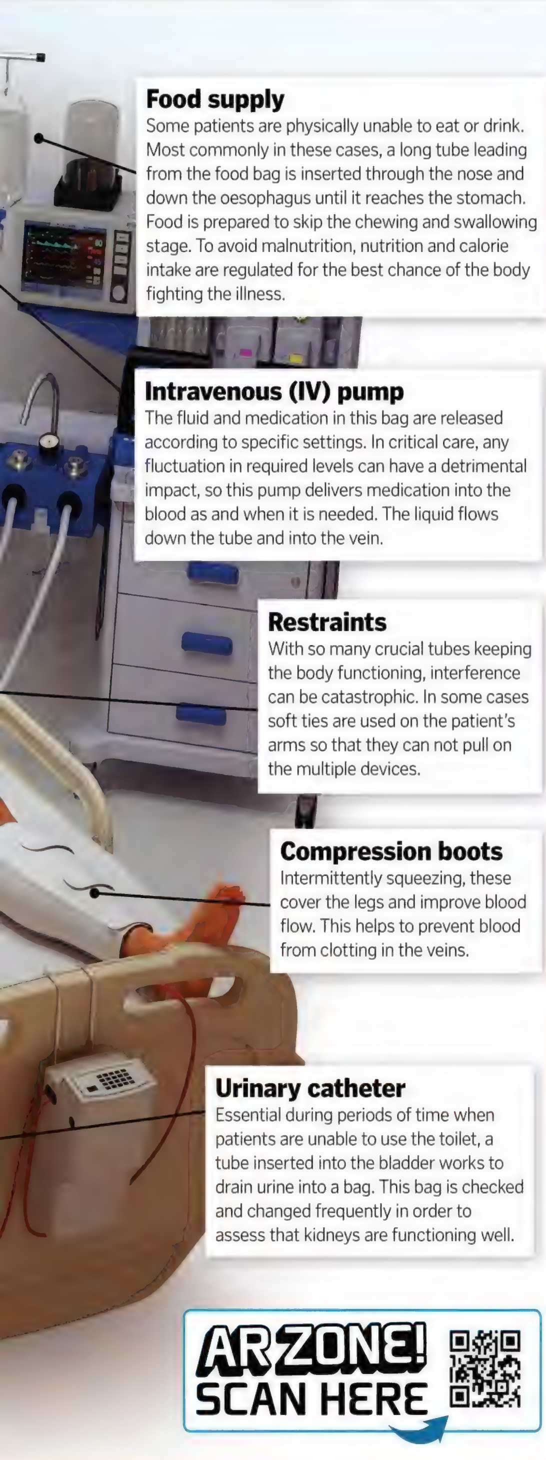
may be just as unexpected, while others might have been anticipating it, having experienced their bodies' slow decline. Critical care follows for a range of reasons: some come straight from the operating room after undergoing major surgery; some are escorted there from the scene of an accident who may have severe burns, broken bones or organ failure and some are monitored after a serious short-term condition such as a heart attack or stroke.

To work on these specialised wards requires a combination of qualities. Called 'intensivists', these medical staff demonstrate an ability to adapt within a workplace where conditions are continuously changing. They need to be able to help with every case that enters through the doors and have the ability to continue performing at the highest level regardless of whether the other battles surrounding them have been victorious or not. These marvellous medics are not only specialised in intensive care, but also have their own area of expertise to put their specific knowledge and skill set to use. To be a specialist you need to be the best of the best, and this is something that is of utmost importance in an environment where anything less could cost someone their life.

170,000
The number of hospital beds in the UK.

Most of us hope death is far in the future, but the reality is that nothing is guaranteed. Life is full of unexpected complications. Inside the ICU, those who are at their weakest now have a better chance of recovery than at any previous time in history. This is due to innovative life-saving technology.

As knowledge of how the human body functions has grown, we've developed machines that have increased in effectiveness, mimicking every function of each human organ when the corresponding organ in a patient is failing. While it's impossible to be in two places at once, electronic sensory



Food supply
Some patients are physically unable to eat or drink. Most commonly in these cases, a long tube leading from the food bag is inserted through the nose and down the oesophagus until it reaches the stomach. Food is prepared to skip the chewing and swallowing stage. To avoid malnutrition, nutrition and calorie intake are regulated for the best chance of the body fighting the illness.

Intravenous (IV) pump
The fluid and medication in this bag are released according to specific settings. In critical care, any fluctuation in required levels can have a detrimental impact, so this pump delivers medication into the blood as and when it is needed. The liquid flows down the tube and into the vein.

Restraints
With so many crucial tubes keeping the body functioning, interference can be catastrophic. In some cases soft ties are used on the patient's arms so that they can not pull on the multiple devices.

Compression boots
Intermittently squeezing, these cover the legs and improve blood flow. This helps to prevent blood from clotting in the veins.

Urinary catheter
Essential during periods of time when patients are unable to use the toilet, a tube inserted into the bladder works to drain urine into a bag. This bag is checked and changed frequently in order to assess that kidneys are functioning well.

Dependency levels

This gradation groups patients based on the severity of their conditions

LEVEL 0

General assistance
Patients at this level are looked after through normal ward care. Patients may need an IV or oxygen using a face mask. They can remain for over four hours without needing to be assisted.

LEVEL 1

Additional support
At this level additional clinical support is required. These patients are at risk of deteriorating or were previously at higher levels of care and are attended to at least every four hours.

LEVEL 2

Organ failure
Level 2 conditions include a single failing organ and those who are at high risk of further complications – such as those having recently undergone a major operation. With likelihood of deterioration in mind, patients are checked hourly or more.

LEVEL 3

Multiple organ failure
At the top level of monitoring, these people have the highest risk of death. To ensure this is prevented as much as possible, in each situation multiple specific machines aim to provide each body's needs.

systems are better armed with the intelligence to respond to changes in a patient's condition and alert staff to their bedside with alarm systems. Bedside technology is working together with the human intellect that comes with years of training. And machines can use imaging to provide a quick and clear insight into the internal functions beneath our skin, allowing staff to better decide their next step in treatment.

With experience, intensivists will have seen most cases that enter the ICU before. They know the protocol and are equipped with the tools to give patients the best chance of recovery. This applies to any disease and injury that causes the body's functions to fail, but what happens when the ICU sees a new case?

This has become the reality recently, with the COVID-19 pandemic putting immense strain on these wards. It's important to remember that while global focus has been on this virus, the ICU continues to see the same range of illnesses it has always had to accommodate for on top of the influx of added patients. While the world was faced with many unanswered questions as people began showing up to hospitals with the new, severe respiratory disease, the medics and their technology were able to see where the body was suffering straight away and provide breathing support through ventilators. This shows that the core principles of care in the ICU remain the same, regardless of the cause.

The intensive care that is provided around the clock in these special wards has been brought into the limelight during recent times, but as global health crises come and go, the ICU never rests. Nobody is immortal, but this ever-improving system is in place to throw every effort into the healing process. Whatever the reason is, every day the ICU sees a diverse mix of talents and technologies all fighting for one thing: a second chance at life.

THE IMPACT OF COVID-19

Throughout the beginning of 2020, the coronavirus pandemic amplified the high pressure put on staff in intensive care units. Usually in these wards a range of critical illnesses are seen. However, with such a surge of COVID-19 cases, wards dedicated to this one virus have been opened.

Most people in these wards need ventilators to survive, and everyone treating patients needs gear to protect them from being infected and ending up in the beds themselves. Hospitals around the world have witnessed strain on these facilities, including limitations in the personal protective equipment (PPE) needed to continue working safely.

One of the most heartbreaking struggles in these tailored wards is the lack of contact with the outside world. While visiting family and friends often make up a substantial percentage of people in the ICU, no visitors are allowed in COVID wards. These unsettling times mean survival is the only way to see loved ones again. For others it has meant having to hear of lives lost with no chance to say their goodbyes.

"Everyone treating patients needs gear to protect them"

NHS Nightingale Hospital London was built in nine days for the intensive care of COVID-19 patients

AR ZONE!

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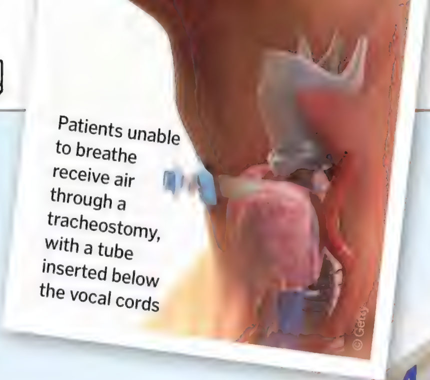
Bedside monitors can display information about the blood, heart and brain at the same time



Patients unable to breathe receive air through a tracheostomy, with a tube inserted below the vocal cords

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70%
Nearly three-quarters of ICU beds are used by adults.

Physiotherapists

Lying horizontally, unable to move for a prolonged period of time and with a body in its weakest condition, patients can lose immense strength and mobility. These specialists stop joints from becoming stiff and help to exercise patients' muscles, but this is not the extent of the help. With many suffering from breathing difficulties, they assist patients with their breathing by strengthening their chest and lungs.

Nurses

When doctors have prescribed the relevant drugs and fluids, nurses are needed to make sure the recommended levels are given and that they are done so correctly. Taking care of a couple of patients at a time, they know how best to care for those in a critical condition and can create a relationship of trust with their patients, putting them at ease through some of the scariest times.

Doctors

The team of doctors in an intensive care unit cover all areas of expertise. This team is led by an ICU consultant who is responsible for overseeing the progress of patients every day and advising the next steps in treatment.

Pharmacists

Seeing patients alongside doctors and nurses, pharmacists can give additional advice on medications. As experts in how medicines should be supplied and applied, they can make sure medication is taken appropriately and intercept any errors before they show negative effects.

Occupational therapists

There is more to intensive care than simply staying alive. The ward is a patient's home for a select period of time, and where possible they often want to gain back small levels of independence. Occupational therapists provide the best solutions to ensure that while they are being treated a patient's daily activities can be carried out to the best of their ability, optimising their mental health as well as physical.

© Illustration by Nicholas Forder

AR ZONE!
SCAN HERE

Speech and language therapists
Speech therapists can improve patients' abilities to speak and swallow during their time in the ward, and in cases where the individual has suffered a brain injury can help improve their affected speech for the future. When tracheostomies are required, which involves making a hole in the patient's throat to insert a breathing apparatus, speech therapists can be of invaluable assistance, ensuring that there will be no unnecessary impact to speech and swallowing as a result.

Dietitians
Incorporating the right foods into your diet is important for even the healthiest individual, but when teetering on the edge of life and death, the body relies on the best nutrition to support recovery. Dietitians monitor food intake and individual responses to ensure patients are being fed the correct volumes and consistencies with the best nutritional value. Choosing the best nourishment is a big responsibility at a time when sick patients have no control over what is put in their bodies.

MEET THE SPECIALISTS

Like heroes of the hospital, each member has mastered a particular superpower

Social workers
The outcome of each medical case often lacks certainty. During their time inside the ward, families and loved ones sometimes need as much support as those on the beds, just in a different way. Social workers provide emotional support to families and visitors at most hospitals, helping them to understand the situation through counselling or helping with financial issues.

In one of the most unnerving sections of a hospital, it is common for visitors and patients to be filled with worry and uncertainty. However, the professionals need to work with quite the opposite emotions, informing those they are caring for, acting decisively and using their expert skills to improve their patients' wellbeing. Each member of the diverse team carries a specialised essential role, but their main objectives are consistent: for patients and loved ones to leave the hospital healthier, happier and, most importantly, alive.

Q&A LEADING AN ICU TEAM

Dr James Bromilow is the lead consultant for intensive care at Poole Hospital in England. With 12 years' experience in this role, he tells us about the unpredictability each day can bring

WHAT IS A DAY IN THE ICU LIKE?

The day is split between looking after patients who are already admitted to the ICU and assessing those on other wards who might need admitting. We can get called to all sorts at any time, from a nine-day-old baby to a 99 year old, from someone with a heart problem to a road traffic accident – it's unpredictable. Patients come to us at all times of the day or night. Every day is different and every day represents different challenges for us.

HOW MUCH DOES A VARIED TEAM OF SPECIALISTS HELP?

Generally intensive care doctors are quite good at dealing with problems with most parts of the body, but when we have a particular specialist problem, we ask our colleagues in other areas to see the patients and help us with their management. Second opinions and further advice can make sure that what we're doing is right.

HOW HAS POOLE HOSPITAL'S ICU COPED DURING THE COVID-19 PANDEMIC?

At the beginning we just didn't know how big the surge of patients was going to be, and we didn't know when that surge was going to come. We didn't know how to treat patients with COVID because we had never seen that before. COVID behaves slightly differently to other viruses with similar reactions, so we had to learn quickly. We were lucky that our surge came two or three weeks after London's. We got information on a daily basis of how the doctors and nurses were treating these patients and that informed the way that we did things. PPE kept our staff very safe. We got low in stocks in the early phases, but thankfully never ran out.

WHAT'S THE MOST CHALLENGING ASPECT OF THE JOB?

Sometimes you have to accept that a patient isn't going to get better, despite your best efforts and treatments. We often have difficult conversations with patients and their loved ones to tell them that the patients aren't going to get better. Then we have to prioritise treating their symptoms, making sure we give them a dignified end to their life. It's a big responsibility, but something we've trained for for many years. It took me 18 years from starting medical school to becoming a consultant. It's never a responsibility that we take lightly. Equally, it can be the most rewarding job when people come in very sick, and within a matter of hours, days or weeks you can get them through their really critical stage and onto the road to recovery. It can be a very gratifying job.

SPECIALISED UNITS

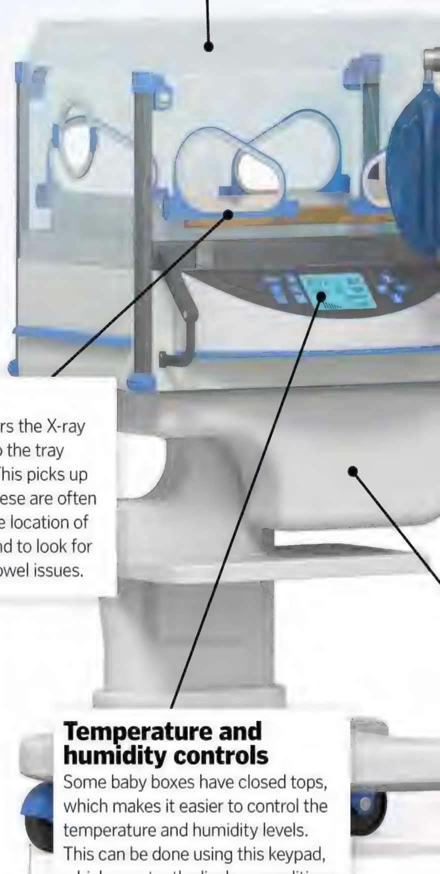
From treating injuries on the road to newborns battling for their lives, how can care be tailored to specific needs?

NEONATAL ICU

Some of the weakest patients also happen to be the smallest

The first few days as a new parent can be some of the most intimidating yet remarkable times. However, in the neonatal intensive care unit, fear and dread come in much heavier doses. When babies are born, they no longer rely solely on their mother. Their bodies have to sustain themselves, but sometimes complications mean they are not able to do this.

In their own ICU exclusively for babies, they are supported by machines until they are hopefully strong enough to be discharged. Some of the most common reasons babies are taken into intensive care include premature births where the baby isn't yet fully developed, low sugar or oxygen levels, breathing problems or infections. The latter is the most common cause of death.



MOBILE ICU

The first responders supplying intensive care on the go

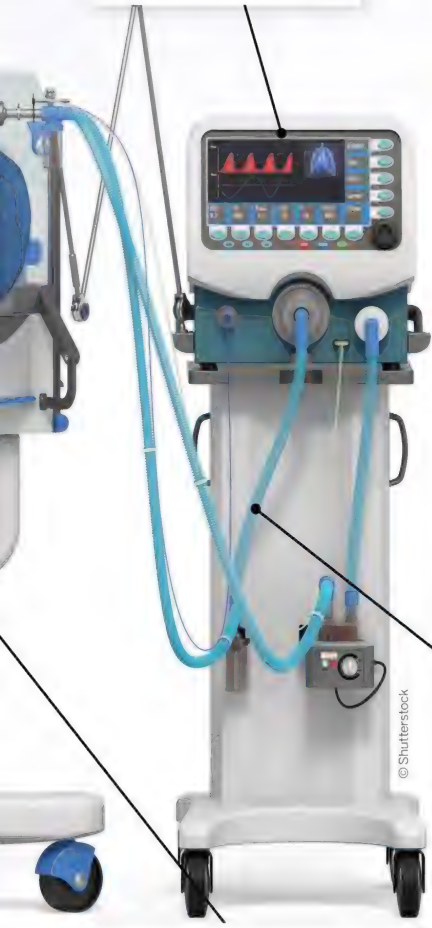
Time is often of the essence when ambulances are called. When someone has been in a severe accident or their health has drastically deteriorated, a life-supporting hospital bed is sometimes just a step too far away. In these cases an advanced care ambulance is sent. This is essentially an ICU on wheels. When the call comes in the severity of the situation is assessed, and if deemed necessary a mobile ICU is deployed. Staff on these vehicles have the most training and are able to fit drips, supply medication and keep the patient functioning during the drive to hospital.

INFECTIOUS DISEASE WARDS

What personal protective equipment can be worn when battling invisible illnesses?

When a patient is admitted to intensive care with an infectious disease, precautions need to be taken to stop this single case spreading. As part of their duty of care, medical staff need to be hands-on to treat patients, but how do you maintain this duty when a simple touch could make you just as critically ill?

Patients who are known to be infectious are often put in isolation. This is a room with all the equipment of the beds in the main ward, but with surrounding walls keeping the infection from spreading. Signs on the door inform staff of the patient's condition, and before entering they are required to wear protective equipment so that they can limit the risk of endangering their own lives as they save others. In cases of a pandemic like the coronavirus, full wards can be dedicated to one common disease.



Vital signs monitor
This machine displays electrical signals from the baby's heart so that hospital staff can easily spot changes. Wires run from the baby's chest to this monitor to relay electrical signals of the heartbeat and breathing rate.

Ventilator
Helping them to breathe, air flows through tubes into their airways. These can be extremely fast puffs which creates a scary sight for the parents as their baby's body moves violently. However, these fast pumps help make sure the tiny air passages in their lungs stay open.

Water tank
Water in this tank is used to humidify the air around the baby. This is essential in premature babies as the outer layer of their skin has not fully formed. Water leaves their body through their skin at a greater rate, and being in humid conditions helps them to retain more.

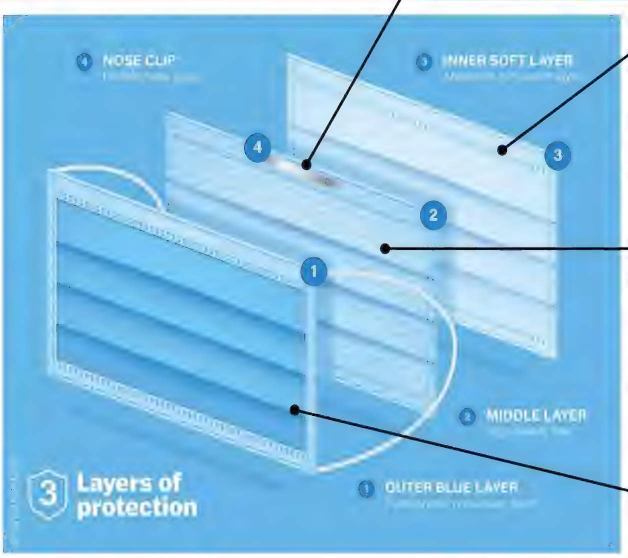
Hairnet
This piece of equipment prevents hair from contamination, as well as keeping it compact. If hair is loose it increases the likelihood of face-touching.

Surgical mask
This fluid-resistant material is hooked onto the ears to keep it in place, covering the nose and mouth. They catch any bacteria or viruses found in liquid droplets, but do not work effectively against airborne microorganisms as these particles are much smaller.

Full-face shield
Providing a better coverage of the face than nose and mouth masks, these plastic coverings are attached using an adjustable band around the head. This shields the face from any airborne disease.

Long-sleeved gown
Disposable full-length gowns catch any sprays and spillages. Upon leaving the ward they are removed, leaving the clothes underneath unscathed and clean.

Gloves
Hands are often most responsible for carrying and spreading disease. Gloves are an essential when examining infected patients and are frequently binned and replaced.



Nose clip
A piece of aluminium bends to fit the face mask around the bridge of the nose. This prevents any gaps between the mask and the face.

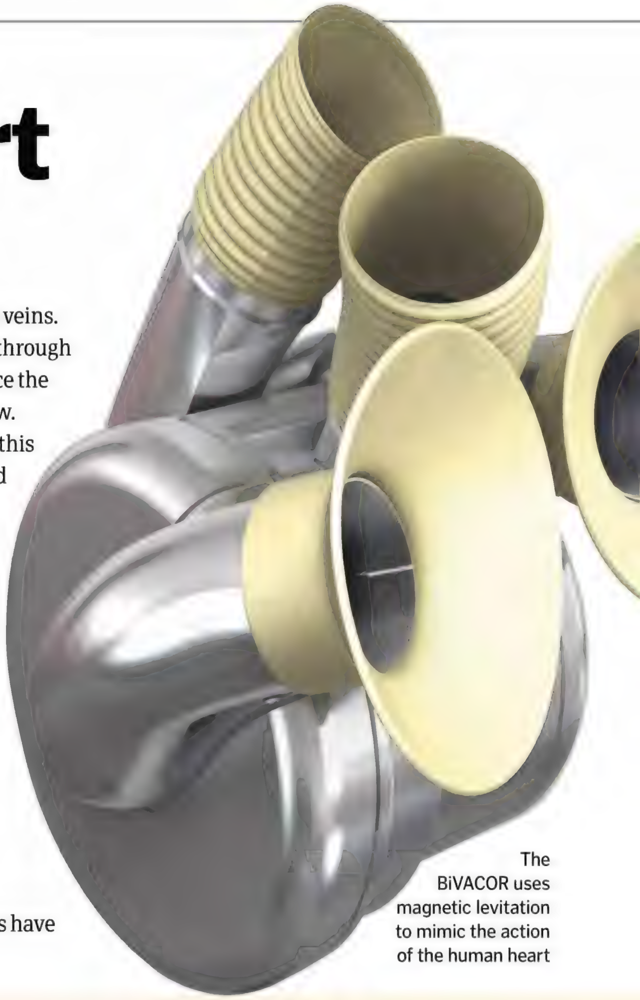
Soft layer
For comfort this layer is soft, absorbing any sweat and spit released during long working hours.

Filter layer
As the middle material, this sheet is a two-way barrier against germs. Stopping tiny particles from travelling through the mask both ways, the dense material works to trap germs.

Outer layer
The outer layer is hydrophobic, meaning it repels water. As the first layer of defence, it is instant protection from any fluids that come into contact with the face.

Inside a bionic heart

Swapping muscle for metal, how does this artificial organ keep blood flowing?



The BiVACOR uses magnetic levitation to mimic the action of the human heart

Cardiovascular disease is one of the world's biggest killers, accounting for 31 per cent of all deaths globally. Although a lot of cases are treatable with a heart transplant, finding a donor is becoming increasingly difficult: only around 4,000 hearts are available globally each year.

The creation of a total artificial heart (TAH) could be revolutionary for saving lives. Several iterations have been tried over the past few decades, but none have had the ability to completely copy the heart's function for more than a few years.

The latest and arguably most promising development of a TAH comes in the form of the BiVACOR, a 3D-printed titanium pump that utilities an autonomous magnetic rotor to circulate blood.

One of the common issues found in previous TAH technology has been the physical wear and tear of a device's moving parts. Using magnetic levitation (maglev), the BiVACOR's central spinning rotor is magnetically suspended inside an electromagnet bearing. As electricity passes through the magnet the rotor spins, propelling the blood around the body's arteries and veins. Maglev prevents physical wear and tear through normal friction, and it is thought to reduce the complications that would normally follow.

> "The rotor spins, propelling the blood around the body's arteries and veins"

Smaller than a can of coke, this compact device is constructed using a form of metal 3D printing called selective laser sintering (SLS). This process involves repeated layers of fine titanium dust being melted by a laser to slowly print the final form.

The BiVACOR has shown promising results during its animal trials, with bovine (cow) subjects surviving the full 90-day test period. However, the device is still in its development stages, and no human trials have been carried out so far.

How important is your pulse?

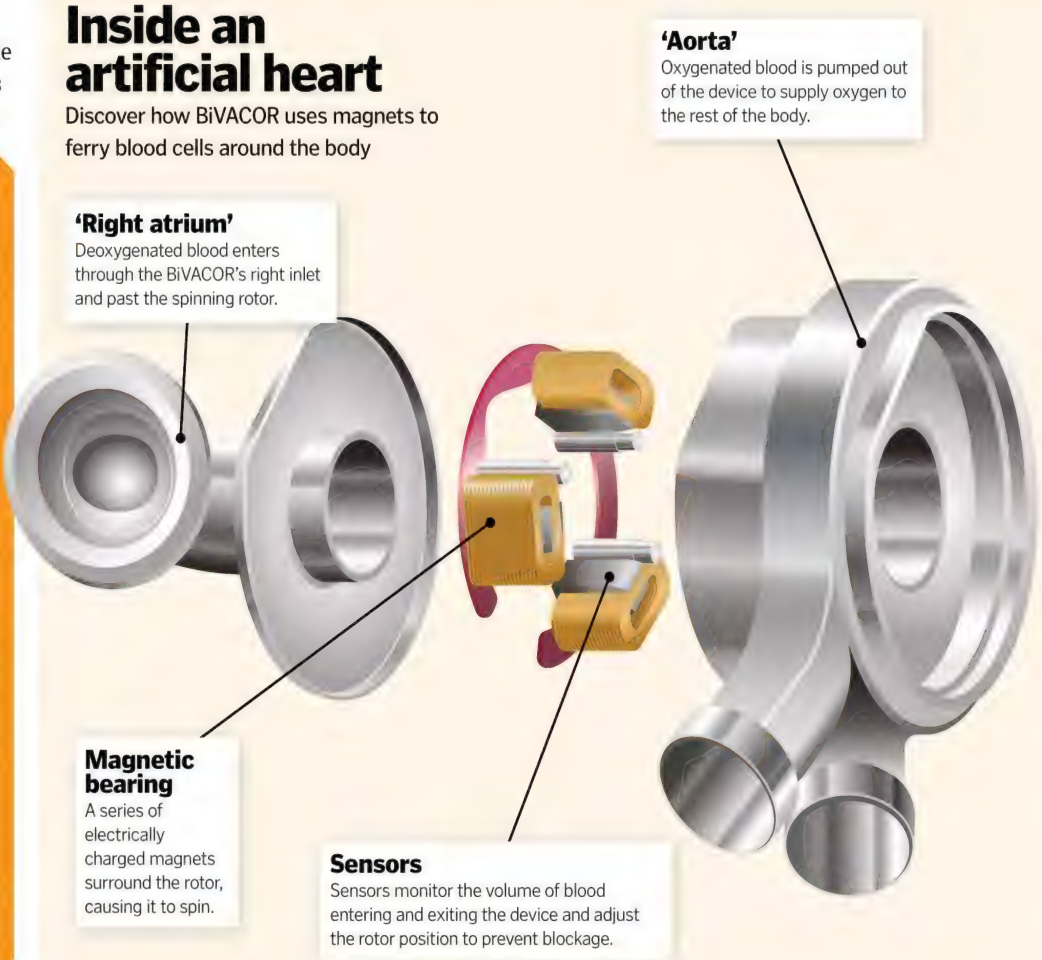
The way our blood moves around the body can play a role in our health. Apart from being an indicator of a beating heart, pulsating blood flow is thought to assist in washing out small blood clots in our arteries, for example.

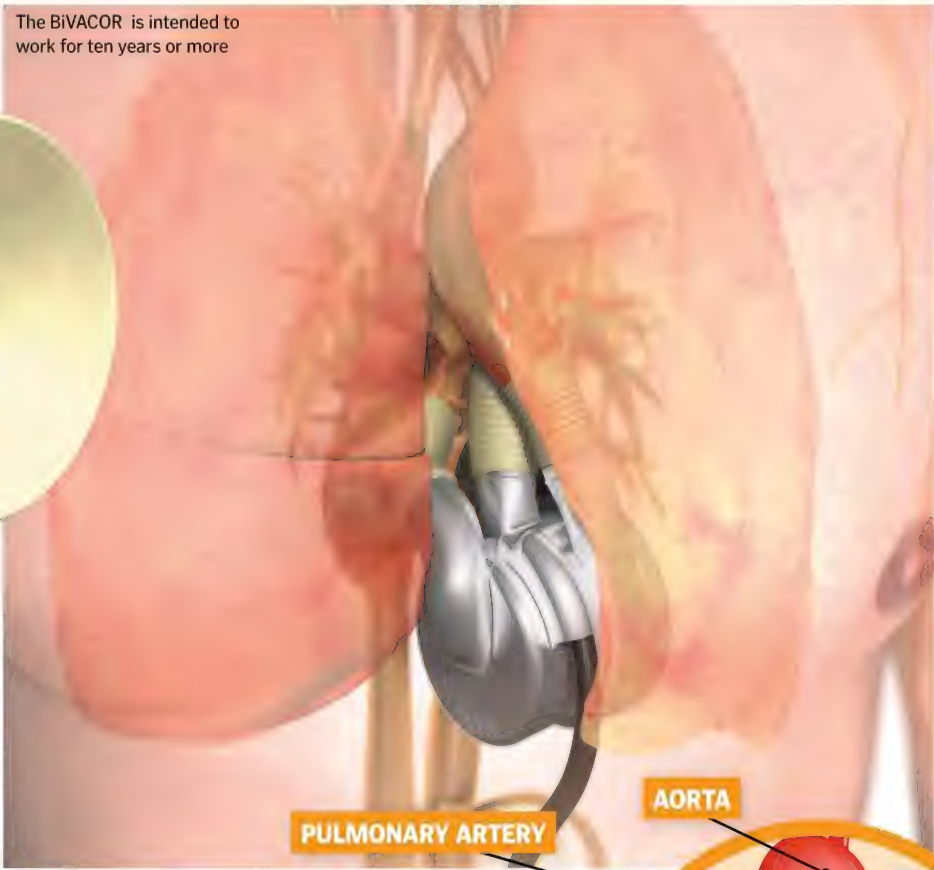
Using the BiVACOR, the maglev rotor continuously circulates blood and removes the presence of a pulse. However, the internal electromagnet can be programmed to mimic each heartbeat with an external device.

The ECG of BiVACOR animal test subjects followed similar patterns to a typical heartbeat

Inside an artificial heart

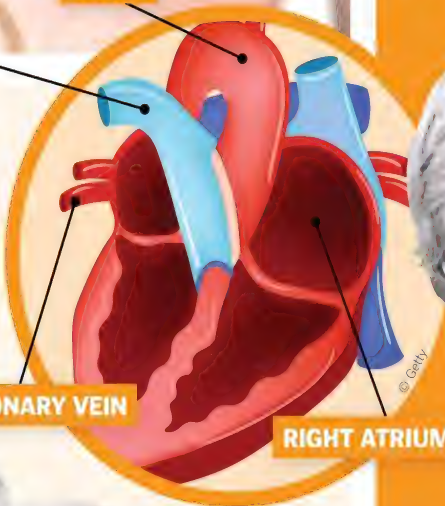
Discover how BiVACOR uses magnets to ferry blood cells around the body





The BiVACOR is intended to work for ten years or more

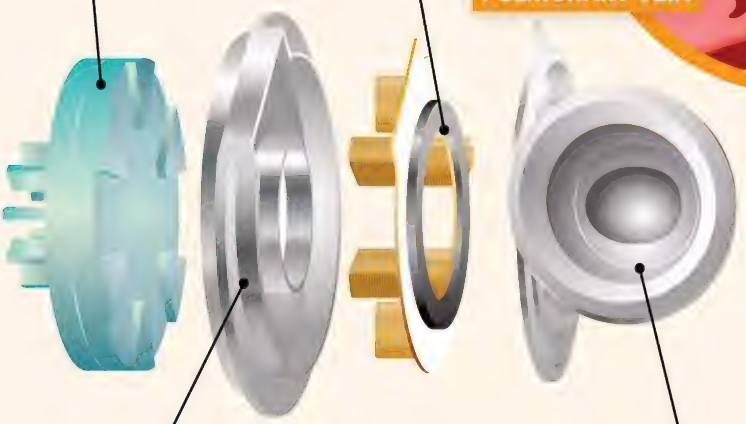
x2 images © BiVACOR



© Getty

Rotor
Separating deoxygenated and oxygenated blood, this centralised rotor is the driving force behind blood circulation.

Motor
Power is sent to the motor via a percutaneous driveline through the skin from an external controller and battery worn by the patient.



'Pulmonary artery'
Deoxygenated blood flows out of the device and heads to the lungs to collect vital oxygen.

'Pulmonary vein'
Oxygenated blood returning from the lungs enters the left inlet.

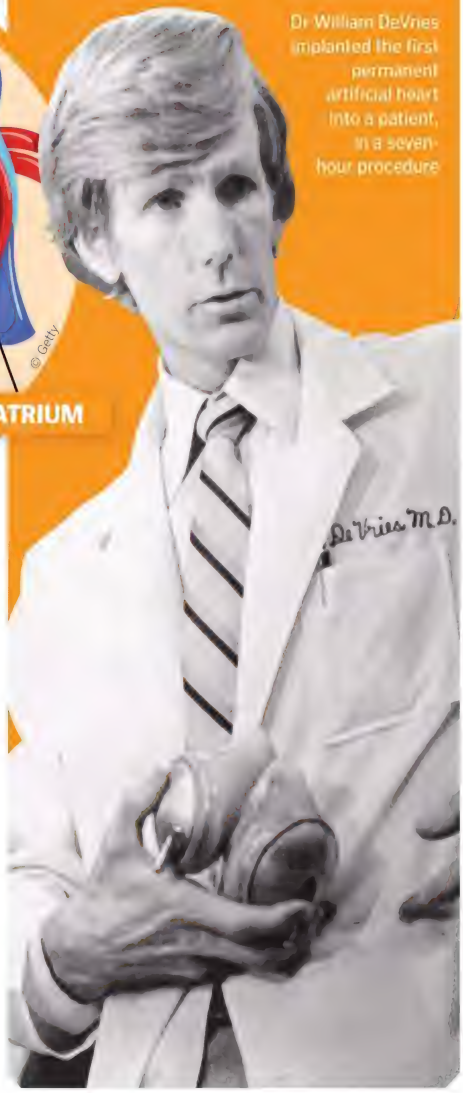
© The Art Agency/Andy Cauchie

A change of heart

The concept of implanting an artificial heart isn't a new one. In the early 1980s American physician Robert Jarvik designed the first artificial heart, later called the Jarvik-7. Made from aluminium and polyurethane, the Jarvik-7 housed two rubber diaphragms to act as the artificial heart's ventricles. With the help of an external compressor, each diaphragm contracted and inflated to mimic the heart's natural pumping action.

Jarvik-7 first saw the inside of a human chest in 1982, lowered in by the hands of American surgeon Dr William DeVries. The first recipient of the human-made heart, a 61-year-old dentist from Seattle, survived for 112 days following the surgery before the device ultimately caused irreversible complications, resulting in his death. Two years later a second attempt was made, with the 52-year-old patient surviving 620 days before a series of strokes brought on by blood clots ended his life.

By 1990 the Jarvik-7 had been removed as an approved form of treatment, but the device gave scientists a valuable insight for future developments.



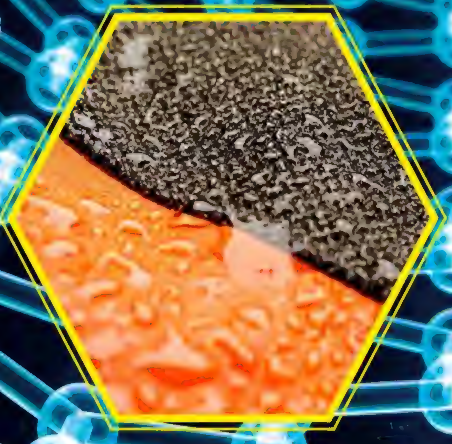
Dr William DeVries implanted the first permanent artificial heart into a patient, in a seven-hour procedure

© Getty

SUPER SUBSTANCES

DISCOVER TEN OF THE WORLD'S STRANGEST AND MOST AWESOME NATURAL AND MAN-MADE SUBSTANCES

Words by **Andy Extance**



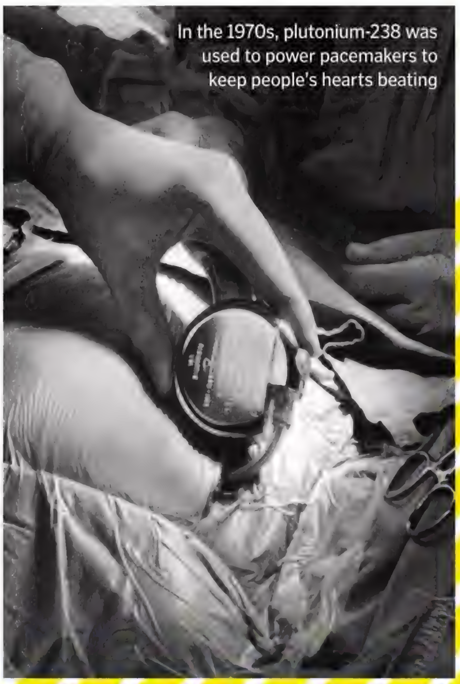
All substances are built up from the same set of 118 elements, so how is it possible that they can be so different? Some elements are interesting in themselves, like gallium, which melts in people's hands, or the powerful nuclear fuel plutonium-238. The atoms of more ordinary elements, like carbon and hydrogen, make up the everyday objects around us. Atoms linked together as molecules even make up our own bodies. Often, carbon atoms are linked together in long chains to create the plastics that we both love and hate. But in some molecular arrangements, carbon can become rather extraordinary.

Organised in flat sheets as graphene and made into an aerogel, carbon becomes the lightest material on record. Carbon also makes the darkest material ever, called Vantablack, in the form of nanotubes that are effectively rolled-up graphene sheets. Or, when combined with hydrogen and fluorine in chains, carbon is part of waterproof textiles that keep us dry.

Mixtures of atoms and molecules, or just mixes of different molecules, can be just as awesome. Ferrofluids combine iron, water and other more complex molecules to give uniquely spiky shapes.

Sometimes the properties that a particular arrangement of atoms provides are useful, sometimes they're dangerous. They can often be entertaining or just flat-out amazing. Sometimes they're all of these at once.

So how is this variety possible? The answers that physics and chemistry offer can be deep – but often they are simple. And understanding them brings more than a moment's pleasure. It also provides us with starting points for new ideas to make the world a better place.



In the 1970s, plutonium-238 was used to power pacemakers to keep people's hearts beating

Ferrofluids were first developed by NASA as a way to move fuel in space

MAGNETIC LIQUID

Metallic droplets that make intricate shapes

DANGER ●● **USEFULNESS** ●●●

Iron is common – it's why your blood tastes metallic. So you might be surprised to know that it also helps to form hedgehog-shaped droplets.

To make these spiky 'ferrofluids', people mix tiny iron particles into a liquid with molecules called surfactants – which is what gives washing-up liquid its cleaning power. The surfactants stop the iron clumping together.

When you put a drop of the liquid near a magnet, the magnet moves tiny iron particles along magnetic force lines with gaps between, like you see with dry iron filings. However, in liquids the molecules gently attract each other. When they meet the air, this creates a force known as surface tension. Surface tension and gravity pull against the magnetic forces, keeping the iron particles in the droplet. Spikes form because ferrofluids channel magnetic force lines, and troughs form in between. Such ferrofluids can be used in electronics and engineering, in products containing magnets, such as speakers.

How ferrofluids spike

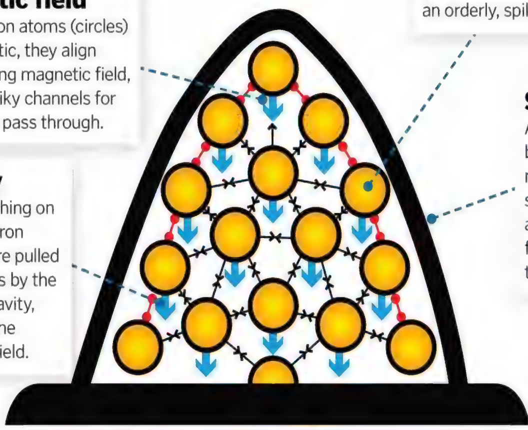
Forces wrestle each other and find balance in unique forms

Magnetic field
Because iron atoms (circles) are magnetic, they align with a strong magnetic field, forming spiky channels for the field to pass through.

Gravity
Like everything on Earth, the iron particles are pulled downwards by the force of gravity, opposing the magnetic field.

Interatomic forces
As the iron atoms align with the magnetic field, they become magnetised themselves, and arrange into an orderly, spiky structure.

Surface tension
Attractive forces between liquid molecules create surface tension, pulling against the magnetic field to bring iron atoms together in spikes.



SELF-HEATING METAL

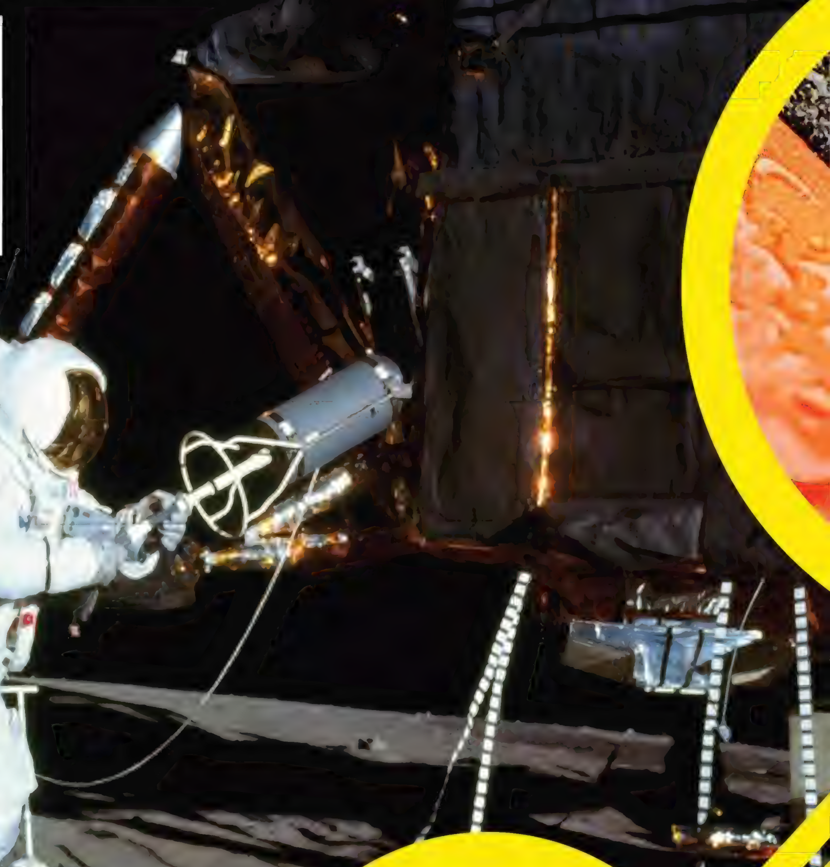
This element is the ultimate power source for space missions

DANGER ●●●●● USEFULNESS ●●○○○

Plutonium is sometimes called the 'most toxic substance known to man' – but it is also a hugely powerful nuclear energy source. A ten-centimetre-diameter plutonium sphere weighing eight kilograms can produce an explosion as big as the bomb that hit Nagasaki in 1945.

Plutonium forms different isotopes, where its atoms have the same number of protons but a different numbers of neutrons. Making it involves bombarding an isotope of the rare radioactive element neptunium with neutrons in a nuclear reactor.

As with all radioactive elements, plutonium-238 slowly decays to lighter elements. Plutonium-238, with 94 protons and 144 neutrons, generates enormous amounts of heat as it decays into uranium-234, with 92 protons and 142 neutrons. Some spacecraft are powered with that heat, like Voyager 1 and 2, which visited planets in the Solar System. Some old pacemakers were powered the same way, but we now keep hearts going with less hazardous batteries.



The heat from plutonium-238 powers many spacecraft, and was used during many of the lunar landings

Plutonium-238-powered voyages

The Voyager probes explored our Solar System's outer planets, helped by radioisotope thermoelectric generators (RTGs)

Eight laptops' worth of power
At first, the RTG produced 157W of electrical power, which halves every 88 years. An efficient modern laptop consumes around 20W.

Radiation shielding
To protect the Voyager probe's other components from radiation damage, the RTG needs to be shielded with materials like beryllium.

Silicon-germanium thermocouple
The heat source is surrounded by a thermocouple device made of silicon germanium, which converts heat to electricity.

Plutonium-238 heat source
Spheres of plutonium-238 dioxide in the centre of the RTG give off heat to power the Voyager spacecraft.

The power released by plutonium-238 can be seen in the glow it releases

SUPER-WATER REPELLANT TEXTILE

Technology that keeps us dry

DANGER **USEFULNESS**

The same coatings used to make some fabrics water repellent can also make non-stick cooking pans. Both use polytetrafluoroethylene (PTFE), which consists of long chains of carbon, hydrogen and fluorine atoms, and is sometimes called Teflon. PTFE is slippery because other atoms struggle to stick to fluorine, so water easily rolls off.

Heating and stretching PTFE threads to eight times their original length transforms them into waterproof materials like Gore-Tex.

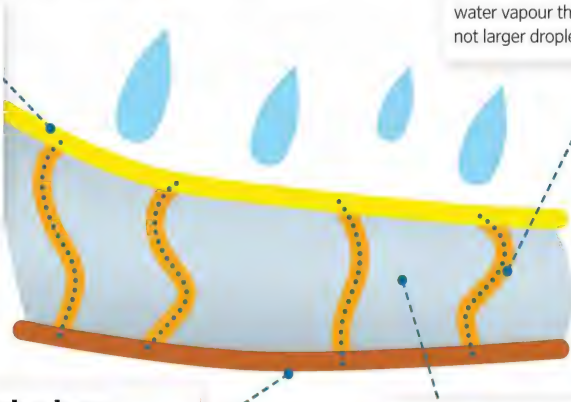
Air makes up around 70 per cent of these materials, leaving small holes that run through it. Alone, water molecules from our bodies are small enough to pass out through them. But lots of water molecules together make droplets about 20,000 times bigger than these holes and can't get inside.

Even more waterproof 'superhydrophobic' coatings emulate lotus flower petals. These petals have rough surfaces, trapping air underneath water droplets. Water droplets are therefore more likely to roll away. Roughening coatings like PTFE works in a similar way.

Water can't pass through the tiny holes in PTFE-based materials like Gore-Tex

Un-holey dryness

Unlike Gore-Tex's holey PTFE layer, hydrophobic textile Sympatex uses a different 'copolymer' plastic

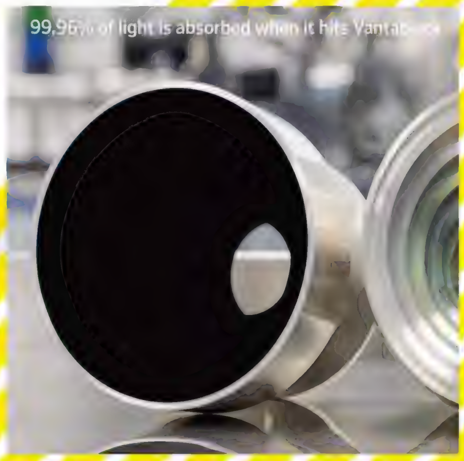


Hydrophilic component
Sympatex uses water-loving or 'hydrophilic' ingredients, effectively forming many tiny channels that suck water vapour through, but not larger droplets.

Optional upper layer
Most Sympatex fabrics include a different material as an upper layer to make them even more waterproof.

Textile lining layer
A porous textile layer takes moisture away from the surface of the skin to the Sympatex membrane.

Sympatex membrane
The Sympatex membrane is a special plastic 'copolymer' that lets water vapour through, without forming holes or absorbing water droplets.



99.96% of light is absorbed when it hits Vantablack

© Surrey Nanosystems

© Surrey Nanosystems

Vantablack absorbs so much light it doesn't produce reflections that normally help define shapes

VANTABLACK

The world's blackest material?

DANGER

USEFULNESS

Seeing Vantablack is more like looking at a hole into nothingness than something painted black. As one of the world's blackest materials, it absorbs 99.96 per cent of all visible light that hits it.

Doing this requires materials made of carbon, connected up into tiny cylinders called nanotubes. In the original Vantablack, they're created vertically on an aluminium foil. The nanotubes are aligned precisely, and under a microscope they look something like a densely packed brush. When light hits the surface, it's trapped inside and between the nanotubes. This stops reflections that could affect measurements, such as in super-sensitive telescopes.

But Vantablack is no longer the very blackest material. Recent research from MIT has produced a rival, with a random organisation of nanotubes that absorbs 99.99 per cent of light.

HOT ICE

Sodium acetate stores and releases heat

DANGER **USEFULNESS**

How can ice be hot? Well, it's not actually ice, as in frozen water. It's a chemical called sodium acetate, which goes from liquid to solid a bit like ice, releasing heat. Heating pads and hand warmers therefore use it.

Some sodium acetate crystals contain water, which helps to store and release energy. When energy is put in as heat, the crystals melt. The sodium acetate then dissolves in the water contained in the crystals. The mixture remains as a liquid when it cools down, but can easily turn back into a solid. All it takes is a little extra push, like when someone presses on a metal disc in a heating pad. Then the liquid crystallises back into solid sodium acetate, releasing heat energy.

© Alamy

Heat pads make use of sodium acetate

INDESTRUCTIBLE, HEAVYWEIGHT GAS

Brilliant for industry, bad for the environment

DANGER **USEFULNESS**

Sulphur hexafluoride hardly ever reacts, which is both good and bad. Strong acids can't break it down, and it doesn't burn. The electricity and temperatures above 1,000 degrees Celsius used in magnesium smelting don't touch it either, which is useful. Magnesium is highly reactive so there is a strong fire risk, but sulphur hexafluoride gas can blanket the process safely.

That's because fluorine atoms surround the sulphur atom at the molecule's centre, protecting it from chemical attack. The same property stops sulphur hexafluoride molecules interacting with each other and forming a liquid or solid. Instead it's a very dense, invisible gas, which lightweight foil boats can even float on. However, it's also a very potent greenhouse gas – and the fact it's so stable is a problem for Earth's climate.

© calpolypomonademos

Sulphur hexafluoride is so dense that foil boats can float on it

GRAPHENE AEROGEL

So light, it floats on air

DANGER

USEFULNESS

When we buy balloons filled with helium, we can forget how rare and expensive this gas is. Luckily, carbon materials known as graphene-based aerogels might provide an alternative. Amazingly, they're the world's lightest material – almost one-eighth as dense as air. A cubic metre weighs just 160 grams, compared to 1,000 kilograms per cubic metre for water.

Graphene is single layers of carbon in its graphite form. Some types of graphene are left on paper when you write with a pencil. However, it's only recently that scientists have realised graphene has various exceptional properties, including strength. Whereas gels are mixtures of solids in liquid, aerogels refer to dispersions of solids in air. One way to make graphene aerogels is mixing graphene with water and 3D-printing it onto a -25-degree Celsius surface that freezes it. You can then remove the ice without melting it using a method called 'freeze drying'.

"The world's lightest material – almost one-eighth as dense as air"

© University at Buffalo

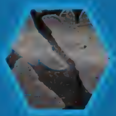
This graphene aerogel is light enough to sit on a ball of cotton

GRAPHENE GOES FLAT OUT

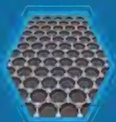
COMPOSITES | ENERGY | DATACOM | ELECTRONICS | SENSOR & IMAGING | BIOMEDICAL TECH

2020 TO 2022

Composites

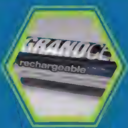


Functional coating and surface modification
Graphene promises thin, advanced protective coatings.



STRUCTURAL MATERIALS

Energy



FAST-CHARGING BATTERIES

ADVANCED SOLAR PANELS

Datacom

ADVANCED OPTICAL COMMUNICATIONS

Electronics

Low-cost printable electronics
Conductive inks containing graphene can be printed to make cheap integrated circuits.

Sensor & Imaging

PHOTODETECTORS AND PHYSICAL CHEMICAL SENSORS

Broadband cameras and spectrometers
Graphene-enabled image sensors can detect many visible and invisible colours, while single-pixel graphene spectrometers can identify many materials. This has multiple applications - particularly space missions.

Biomedical Tech

Biosensors
Graphene withstands our soggy insides better than most electronics, meaning it might bring better at monitoring of what's happening inside us.

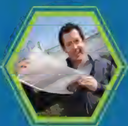
2023 TO 2029

Composites

MULTIFUNCTIONAL CONSTRUCTION MATERIALS

Water treatment and desalination
Graphene sheets can serve as a mesh that separates water molecules in seawater from salt's sodium and chloride ions.

Energy



FLEXIBLE SOLAR CELLS

SUPERCAPACITORS FOR WAREHOUSES

MULTIJUNCTION PHOTOVOLTAICS

Datacom

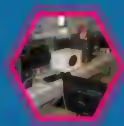
Advanced network infrastructures
Graphene can be used to help produce lasers that can pulse quickly, which might help send internet data faster.

Electronics

HIGH-FREQUENCY ELECTRONICS

Flexible devices
Graphene is highly conductive, thin and strong, making it ideal for use in lightweight and potentially flexible electronics.

Biomedical Tech



Neural interfaces
Scientists should be able to implant thin and robust graphene electrodes into brains.

2030 & BEYOND

Energy

Fuel cells for vehicles
Fuel cells need membranes that let only protons through, and graphene has been shown to do this better than existing materials.

Datacom

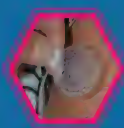
6G AND BEYOND WIRELESS NETWORKS

On-chip optical data
Graphene could produce components that might enable laser-based signals to replace electrical signals within electronic chips.

Electronics

Spin logic devices
Low-power, low-volatility and high-speed electronics

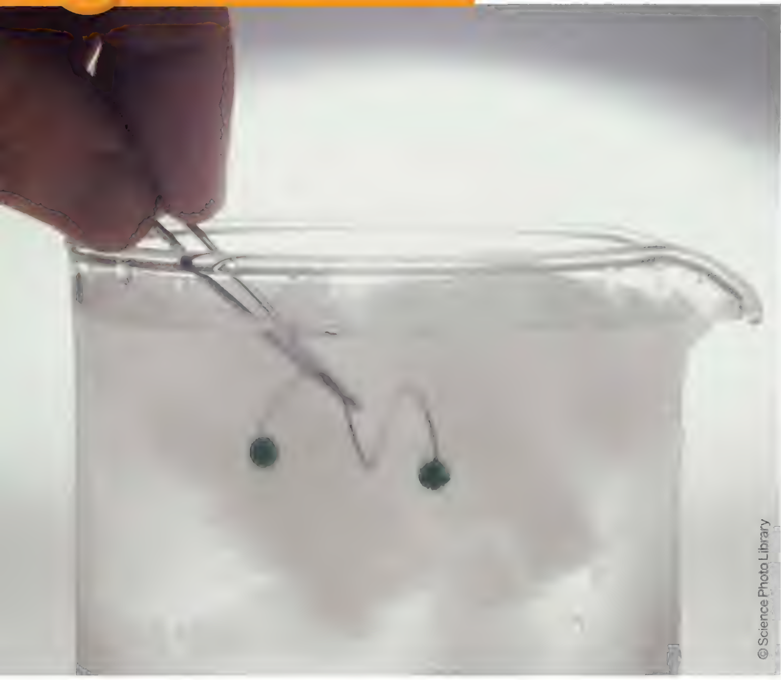
Biomedical Tech



Drug delivery
Drug molecules could sit on graphene sheets, which could carry them into our bodies and help protect them.

BIOELECTRIC IMPLANTS

Source: NASA; SetPoint medical / Wiki; MBirkinoz; BCIT; Peretz Partensky; Mado Merisalu; Devilbuse; AlexanderAIUS; Robertvan1; Pang Ka kit; Ken-ichi Nakagawa; chatawat; Superdiddy; US Navy; Angeloleithold; Anita Fors; Asurnipal; CSIRO; Ludovic Hirlimann; Rogilbert-commonswiki; Epop; Anders Sandberg



METAL THAT HAS A MEMORY

This clever alloy can shift its own shape

DANGER ● ○○○○ **USEFULNESS** ●●●● ○

Sometimes, a nitinol wire is straight and bendy like most other metals. Heat it up, however, and it can spring into a pre-imprinted shape. This 'shape memory' is helpful in medicine, for example as stents that keep blood vessels open. When cool, nitinol can be squashed and inserted by keyhole surgery. Once put in place, body temperature drives it back to its original size and shape.

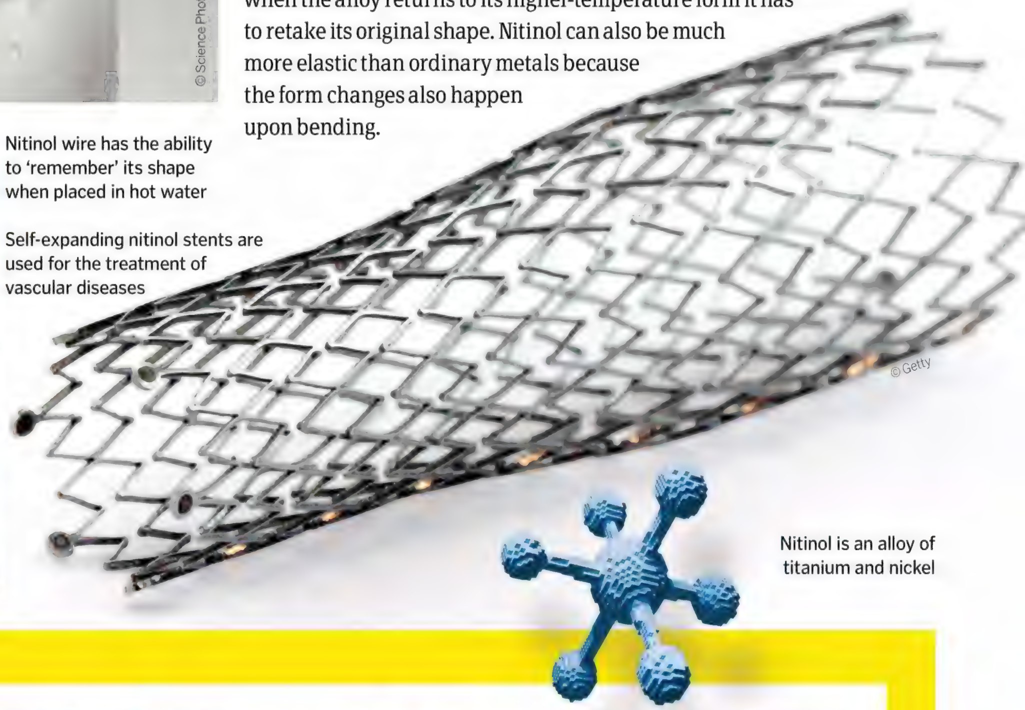
The change comes because the nickel and titanium atoms in the alloy organise themselves in two ways at different temperatures. After cooling to the lower-temperature form it can be put into one shape, but when the alloy returns to its higher-temperature form it has to retake its original shape. Nitinol can also be much more elastic than ordinary metals because the form changes also happen upon bending.

© Science Photo Library

Nitinol wire has the ability to 'remember' its shape when placed in hot water

© Getty

Self-expanding nitinol stents are used for the treatment of vascular diseases



© Getty

Nitinol is an alloy of titanium and nickel

TOUCH-SENSITIVE EXPLOSIVE

Nitorge Triiodide is extremely unstable

DANGER ●●●●● **USEFULNESS** ● ○○○○

Apply the slightest pressure and nitrogen triiodide blows up. It's often made as a black powder that can be kept damp to stop it exploding unexpectedly. If you have more than a small sprinkling of it, you're in danger. But just a little smear can be fun in the hands of an expert.

When something touches dry nitrogen triiodide it quickly decomposes to form nitrogen gas, making a loud crack and purple smoke. The rapid expansion from solid to gas drives the explosion. It also expels iodine, the coloured gas.

Many such explosives are useful, but only if they're stabilised so they can't be set off by accident. However, nitrogen triiodide is hard to stabilise, meaning it's mainly used for entertainment.

© Science Photo Library

Nitrogen triiodide is hard to keep stable – any pressure when it's dry and it will explode

5 FACTS ABOUT MELTING METALS

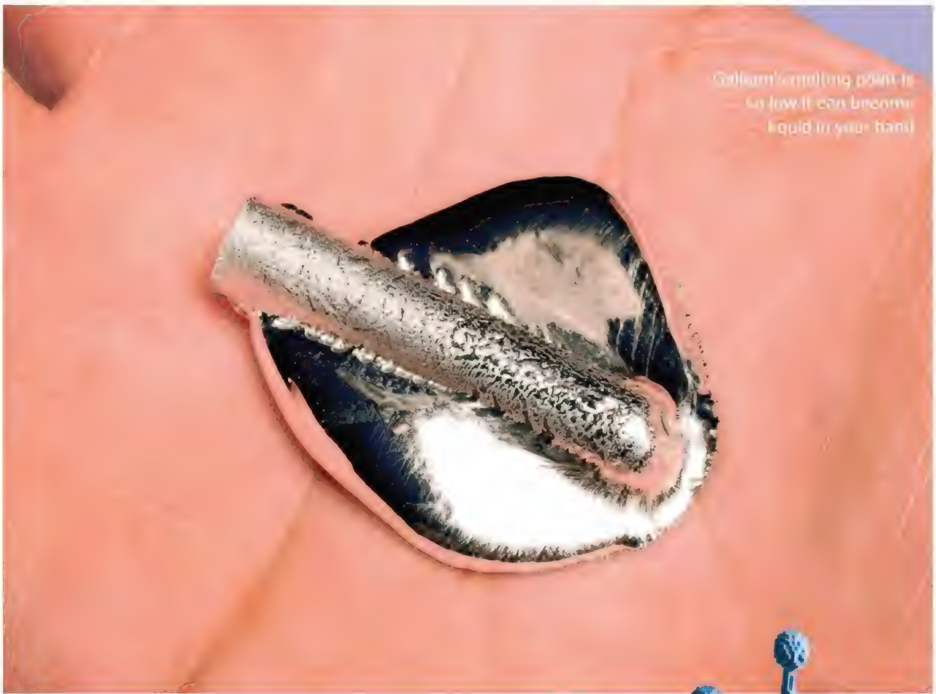
1 Mercury -39°C
Often called quicksilver, liquid mercury was popular in scientific instruments such as thermometers, but as it's toxic it's less common today.

2 Copernicium Roughly 10°C
This synthetic metal decays to other elements within seconds, but it should be liquid at room temperature – if enough was ever made at one time.

3 Caesium 29°C
Like other metals in its periodic table group, caesium melts easily but also catches fire in air, so using it is rather difficult.

4 Indium 157°C
This soft element is important in electronics, forming transparent alloys that sit on the front of many electronic screens.

5 Bismuth 271°C
Bismuth melts readily to form beautiful, colourful spiral crystals and mixes with other metals to make easily shaped alloys.


Gallium's melting point is so low it can become liquid in your hand

© Alamy

GALLIUM MAGIC

It melts in your palm and lights up our lives

DANGER USEFULNESS

If you've seen the disappearing spoon trick, you've probably heard of gallium. This metal is only just solid at room temperature, melting at 29.8 degrees Celsius. Holding it in the palm of your hand is enough to slowly melt it to a silvery puddle. Putting gallium in a cup of tea works even quicker.

That's because gallium doesn't form the standard high-stability metal structure, where all the atoms are held tightly together. Instead gallium forms clusters of just a few atoms, in structures that break down easily.

You might not have seen pure gallium, but you probably have gallium at home, combined with other elements. Gallium-based compound semiconductors are well-suited to turning electricity to light, and light into electricity. Gallium nitride is used to produce blue, green and white LEDs. Gallium arsenide is used to make red LEDs and solar cells used in space.

130 GIGAPASCALS
This tensile strength makes graphene the strongest material ever discovered

87.7 YEARS
The time it takes for half a plutonium-238 sample to decay

58°C
Sodium acetate's melting point lets hot water recharge 'hot ice'

BOB GORE DISCOVERED GORE-TEX BY ANGRILY YANKING ON PTFE THREAD

99.96%
Vantablack absorbs almost all the light that hits it

BOTH PLUTONIUM-238-POWERED VOYAGER PROBES HAVE LEFT OUR SOLAR SYSTEM

23,500
Sulphur hexafluoride harms the environment 23,500 times more than carbon dioxide

1973
Ferrofluids first helped remove heat from speakers in the 1970s

Keeping cold to live forever

Cryonic preservation relies on the science of the future to cure disease and even cheat death

Preserved bodies are stored together in special 'sleeping bags', in this supercooled container

The concept of death is difficult and frightening for many, and the search for immortality dates back centuries. From alchemy and the elixir of life to spending eternity as a cyborg, people have dreamed up numerous schemes for evading the inevitable. One approach that claims to have a scientific foundation is cryonics – the preservation of human bodies by freezing or deep cooling (known as vitrification).

Cryonics takes place after a person is legally dead. Their body or head is frozen and stored indefinitely in a chamber, in the hope that scientists in the future will discover ways of bringing them back to life, reversing any damage caused by the preservation process and curing the disease or condition that caused their death. Cryonicists believe that, as long as death was not caused by trauma and the brain remains intact, technology yet to be invented will allow full revival; suggestions for this future technology include cloning, nanomedicine and copying the mind onto a computer.

Storing frozen bodies was first proposed in 1962 in Robert Ettinger's book *The Prospect Of Immortality*. In 1967 Dr James Bedford, a retired psychology professor, became the first person to be cryonically frozen. Since then around 400 people have joined him in suspension, and it's estimated that 3,000 people around the world have plans to be frozen and stored rather than buried or cremated. Four facilities offer cryonic preservation – one in Russia and three in the US.

Despite a number of fierce supporters, cryonics is largely regarded as a pseudoscience, with the practice denounced by the majority of the scientific community and facilities accused of giving false hope.

"Their body or head is frozen and stored indefinitely in a chamber"

Keeping cool

While the feasibility of cryonics is debated, cryopreservation – preserving cells, blood and tissue by cooling them to extreme temperatures – is an established process that has many medical and veterinary applications. Frozen sperm cells were first successfully thawed and used for IVF in 1954, and egg cells, sperm and embryos can now be stored for numerous years to offer reproductive options to those undergoing cancer treatment or sterilisation.

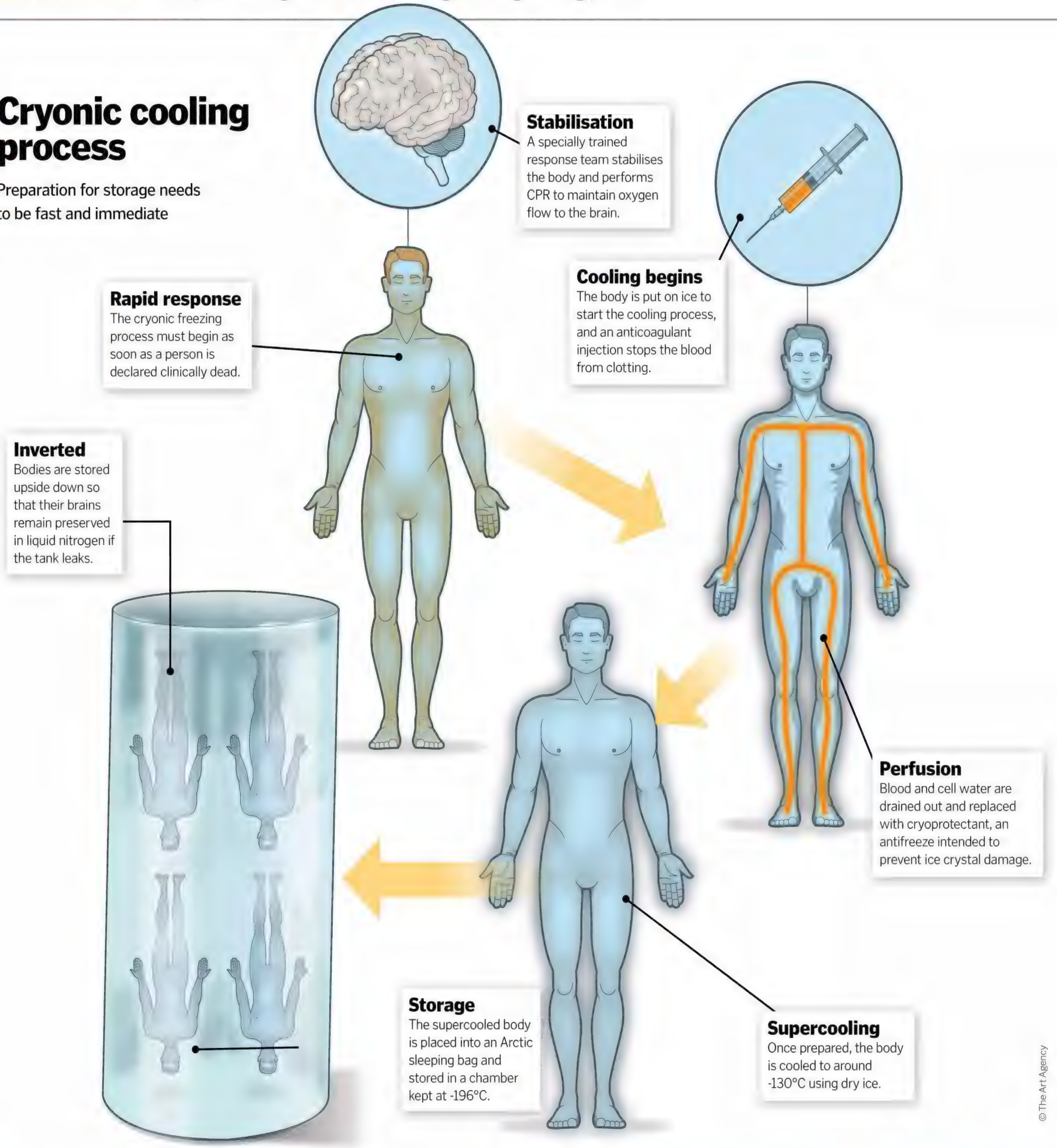
Organs used in transplants must be kept refrigerated while they're transported between the donor and the recipient. To date only a handful of rat and rabbit organs have been successfully frozen, thawed and transplanted, as large tissues are easily damaged when crystals form during freezing, but it's hoped that future advances in cryopreservation will allow human organs to be stored for longer. Donated organs currently remain viable for just a few hours; freezing would mean they could be stored for much longer, reducing transplant waiting lists.

Sperm, egg cells and embryos can be frozen for later use in fertility treatment

Cryonics response teams practise on a dummy, training to prepare bodies as quickly as possible

Cryonic cooling process

Preparation for storage needs to be fast and immediate

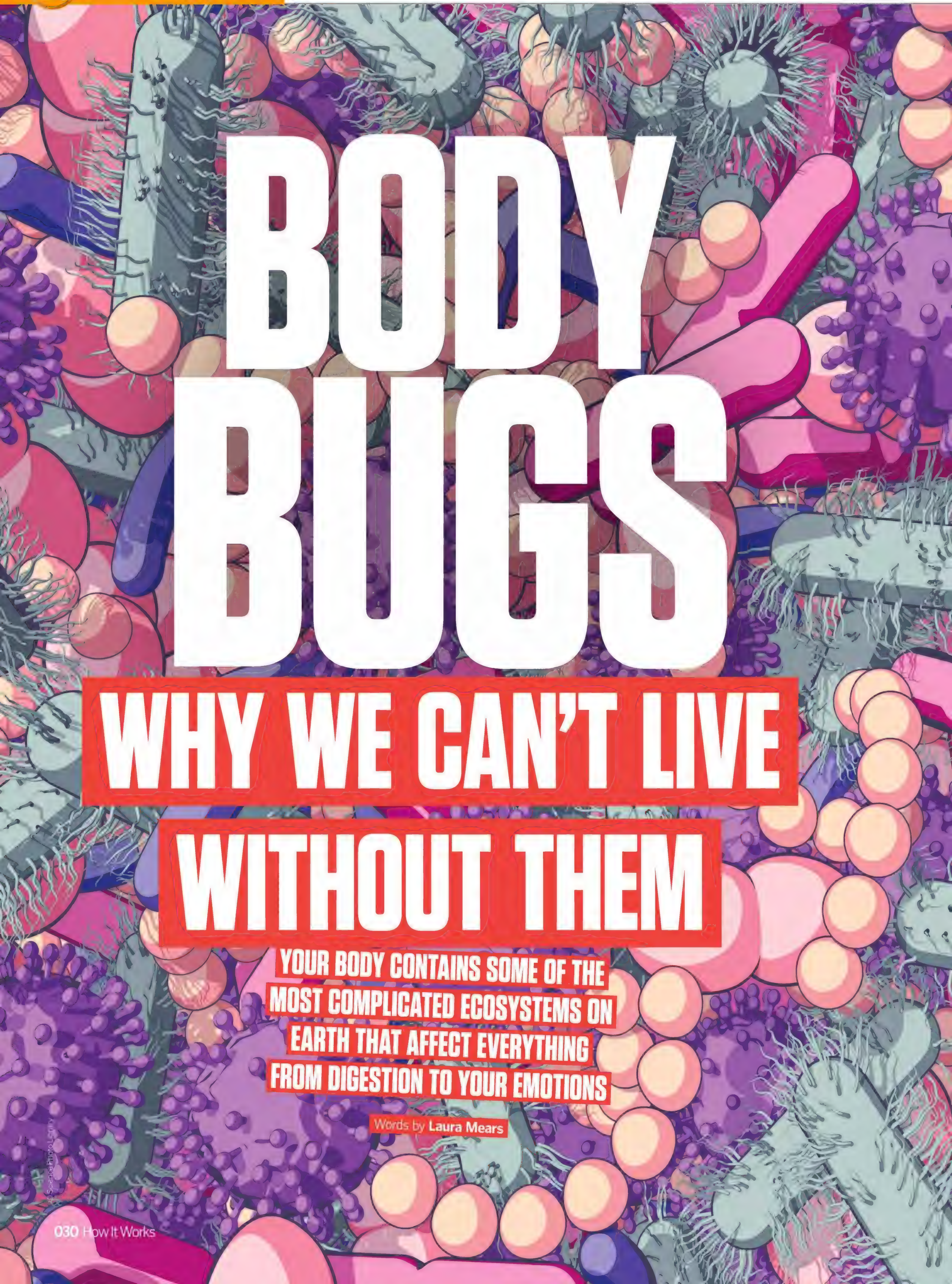


Back from the dead

Humans may currently be unable to recover from being frozen, but it's a normal part of life for other organisms. Wood frogs living in Alaska freeze when the unforgiving winter arrives – their hearts, blood and breathing stop entirely. Anyone coming across a solid wood frog would be forgiven for assuming it was dead, but come the spring the amphibian thaws and hops off to resume its usual business.

It turns out that Alaskan wood frogs produce a natural antifreeze. This cryoprotectant stops ice crystals from forming within the cells and damaging the body, allowing the frogs to shut down and hibernate for seven months each year.


When temperatures rise in spring, wood frogs thaw, rehydrate and carry on



BODY BUGS

WHY WE CAN'T LIVE WITHOUT THEM

YOUR BODY CONTAINS SOME OF THE MOST COMPLICATED ECOSYSTEMS ON EARTH THAT AFFECT EVERYTHING FROM DIGESTION TO YOUR EMOTIONS

Words by **Laura Mears**

DID YOU KNOW? *If you counted up all the unique genes in human gut microbes, you'd find more than 3.3 million*

Your body is teeming with life. In every nook and cranny, there are miniature ecosystems bursting with bacteria, archaea, fungi, protists and viruses. They form a vital part of your biology, digesting your food, interacting with your immune system and even affecting your mood. Just as different plants and animals live in different habitats on Earth, different species of microbe colonise different parts of your body. The skin on your arms and legs is dry and the temperature is unpredictable, like a desert, so few species are hardy enough to make it their home. But the lining of your gut is warm, wet and full of nutrients, like the tropics, supporting a vast diversity of microscopic life. The microbe communities found in each tiny body ecosystem are known as 'microbiota', and their genomes as 'microbiomes'.

Analysing these miniature ecosystems can be tricky, but techniques have advanced rapidly in recent years. One way to understand body bugs is to take swabs and samples and grow them in petri dishes. But this doesn't show the whole story. Many microbes that live happily inside our bodies cannot survive on a dish in a lab, so we never see them. Now, with modern gene-sequencing techniques, it's possible to detect the signatures of these hidden body bugs, and the results are astonishing. As it turns out, we're more microbe than human, and our microbiomes are more unique than our genes.

Old estimates suggested that bacterial cells outnumbered our own cells ten to one. But recent science is a bit more conservative. It's likely that there are between 30 and 50 trillion bacterial cells inside you right now, compared to just 30 trillion human cells. That means that we are only half human at best. What's more, while we humans share around 99.9 per cent of our DNA with each other, our internal ecosystems are nowhere near as similar. Compare our gut microbes and we only share between 80 and 90 per cent of the same genes.

Some scientists think that we should stop thinking of ourselves as individuals and start thinking of ourselves as ecosystems called 'holobionts' – a word that literally means 'whole organism'. This approach helps to make sense of the massive impact our body bugs have on our health. Our microbes don't just ride around inside us, they form an integral part of our biology; we need them as much as they need us.

Take the gut, for example. It's the richest ecosystem in your body, thanks to you. The food you eat provides a constant supply of nutrients, supporting well over three-quarters of the bacteria that call you home. But they aren't freeloading;

gut microbes are a vital part of your digestive system. Bacteria have genes that we don't, which allow them to do metabolic tricks that we can't. This means that they can digest food that our bodies wouldn't otherwise be able to break down. They can also make essential vitamins that we can't produce on our own.

Having microbes in our intestines lets us extract much more nutrition from the food that we eat. In Japan, for example, some people have a gut bacteria species called *Bacteroides plebeius*. It comes from the seaweed in their diet, and it makes an enzyme that can digest complex sugar found in red algae. Without the enzyme, the sugar would just pass straight through. Thanks to the bacteria, the sugar becomes a new source of energy.

Bacteria also seem to help keep the lining of our gut safe. Our intestines need to be able to absorb nutrients without allowing allergens, toxins and bad bacteria to get into the body. In mice, killing certain gut bacteria can trigger a peanut allergy. Restoring the bacteria reverses the effect. The bugs seem to be able to stop dangerous peanut proteins getting into the body.

The ecosystem in our intestines is essential for our survival. However, like any other ecosystem on the planet, maintaining a healthy community is a delicate balancing act. Our guts support hundreds of species, and if this complex mix gets out of balance, it can spell disaster. Problems with the microbiome have been linked to all kinds of diseases, from acne and diarrhoea to diabetes and cancer.

Helicobacter pylori bacteria have tails, called flagella, which help them swim around the stomach lining

© Getty

"It turns out, we're more microbe than human"

Work to unpick the role microbes play in our health is still in its early stages, but there are some links that are starting to become clearer. Genetics and lifestyle both have important roles to play in how we interact with our gut microbes.

One way that scientists have been learning about this is by looking at mouse poo. Analysing the leftovers of a meal can tell us how much energy the mice have managed to extract from their diet. When mice have gene mutations linked to obesity, everything changes. Mice with one type of mutation were able to get more calories from the same amount of food. Mice with a different mutation wanted to eat more. In both cases, it seemed that their gut bacteria were partly to blame.

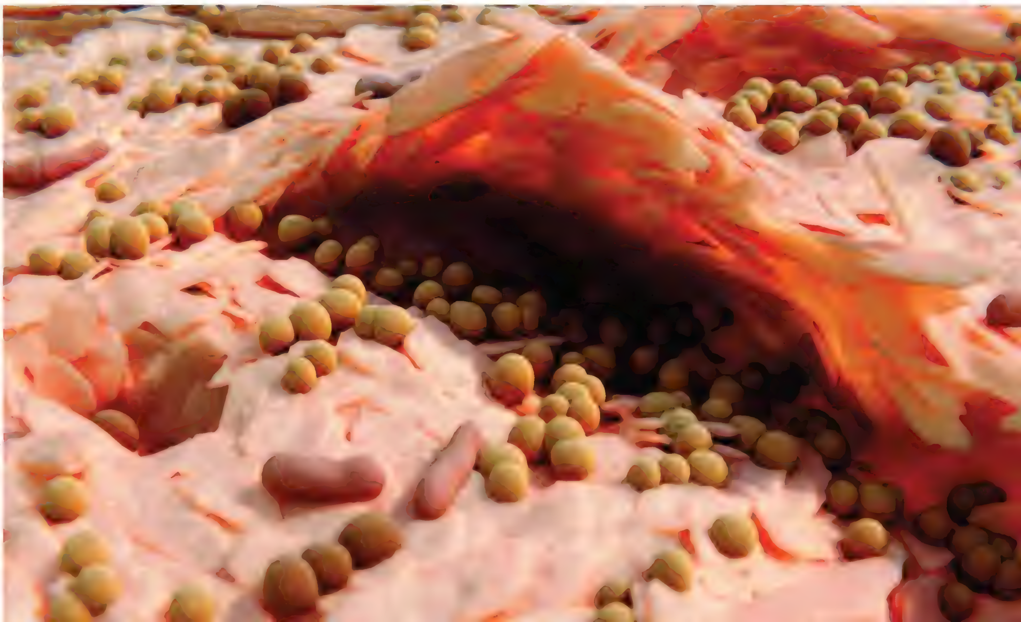
Gut bacteria are also in tune with our lifestyles. Eating lots of meat makes them switch on protein-digesting enzymes, while crunching through vegetables encourages them to turn on enzymes that break down complex carbohydrates. This is hugely beneficial for both us and the microbes.

We can't digest all the fibre from plant-based foods on our own, and without fibre, good bacteria can't survive. So we work together. The more fibre you eat, the more bacteria you can support, and there are benefits for you too. Fibre-eating bacteria make fatty acids, which nourish your gut cells, help to maintain your gut barrier and reduce inflammation.

So far, the focus has mostly been on the intestines. They tend to get all the attention when it comes to microbes because they're easily the richest ecosystem in your body. This is simply because the gut is full of nutrients. However, just because other parts of the body don't have as much food for the microbes to eat doesn't mean they don't have their own microscopic communities.

Take the skin, for example. Adults have around two square metres of skin, a huge habitat for microbes. Most of it is cool and slightly acidic, a tricky place for microbes to make their home, but there are

Staphylococcus aureus bacteria live between the folds of your skin



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When good bugs turn bad

Around half of us carry *Staphylococcus aureus*, little round cells that clump together like bunches of grapes in the folds of our skin, inside our mouths and up our noses. They're mostly harmless, but like many good body bugs, these bacteria are opportunistic pathogens: if they manage to get inside our tissues or into our blood, they can turn nasty.

Staphylococcus aureus doesn't harm healthy skin, but if it gets into an open wound it can cause painful and dangerous infections. Normally these infections are easy to treat with a type of antibiotic called penicillin. However, every time we use antibiotics to treat infection, we give the bacteria in our bodies a chance to develop new defences.

© Getty

Lab tests can find out which antibiotics work best against which strains of bacteria

havens among these deserts, especially in folds and crevices.

Warm, damp creases in the skin, like the belly button, attract bacteria like *Staphylococcus aureus*. Glands, like those on the face, attract species like *Propionibacterium acnes*, named after the spots it causes when it grows too fast. Each little crack forms a tiny ecosystem with its own unique community of body bugs.

Different sets of microbes live inside the ear, on the edge of the nose, up the nostril, in the armpit and in the crease of the elbow. They help to protect the skin from colonisation by more dangerous, disease-causing bacteria and fungi. They also coach the immune system, training it to prevent infections by parasites.

These microbes also form part of your unique body-bug fingerprint. The bacteria that colonise our hands leave telltale traces on everything we touch. The signatures they leave behind are so specific that not only can you tell which person touched an object, you can even tell which finger. Your miniature ecosystems are as unique as you, and without them, you wouldn't be here.

How do babies get their body bugs?

The microbes that inhabit our bodies change throughout our lives, but we get our first residents when we're still in the womb. The placenta has its own microbiome, including bacteria that help to convert chemicals into vital vitamins.

The next big dose of microbes comes during and shortly after birth, and different babies pick up different combinations of body bugs. Babies born by caesarean section pick up lots of skin bacteria, while babies born vaginally get a combination of bacteria from the skin, gut and birth canal. Babies born at home pick up a richer set of bacteria than those born in hospitals. Breast-fed babies get a gut microbe boost thanks to tiny bacteria-feeding sugar particles called human milk oligosaccharides.

When babies transition to solid foods, everything changes again as new bacteria enter their digestive system. If they catch an infection or take antibiotics, this can also change their body-bug mix.

© Getty

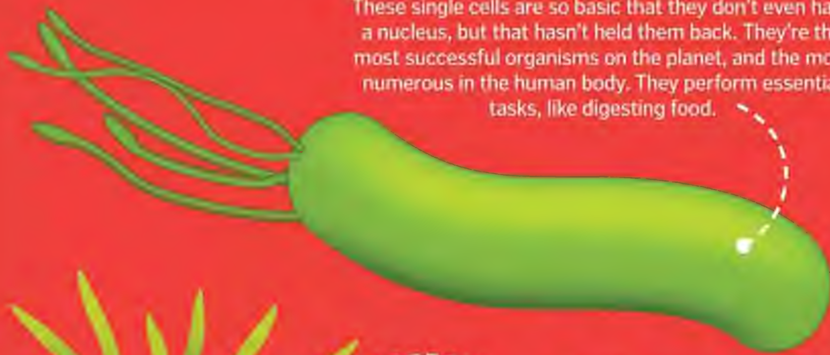
Newborn babies pick up microbes from their environment

MICROBES UNDER THE MICROSCOPE

YOUR BODY ECOSYSTEM IS TEEMING WITH DIFFERENT KINDS OF MICROSCOPIC LIFE

Bacteria

These single cells are so basic that they don't even have a nucleus, but that hasn't held them back. They're the most successful organisms on the planet, and the most numerous in the human body. They perform essential tasks, like digesting food.

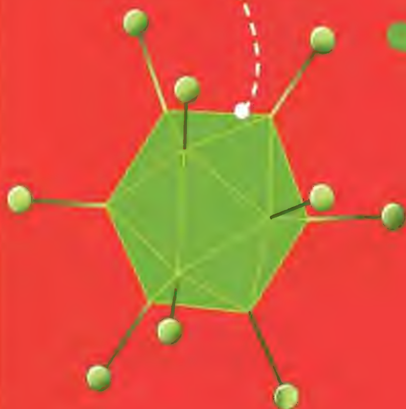


Archaea

These microbes look a bit like bacteria, but they have completely different chemistry. This allows them to do something special – make methane. It's a critical step in human digestion, and the source of some of our gut gas.

Viruses

These small bags of genetic code hijack cells and turn them into virus factories. Some infect us directly, while others attack the organisms that live inside us. This isn't always a bad thing: it helps to keep our microbes in balance.



Fungi

There aren't many types of fungi inside our bodies. Those that do call the human ecosystem home are mainly yeasts. They fight with bacteria for space on our skin, and if an opportunity arises, they sometimes invade and cause disease.

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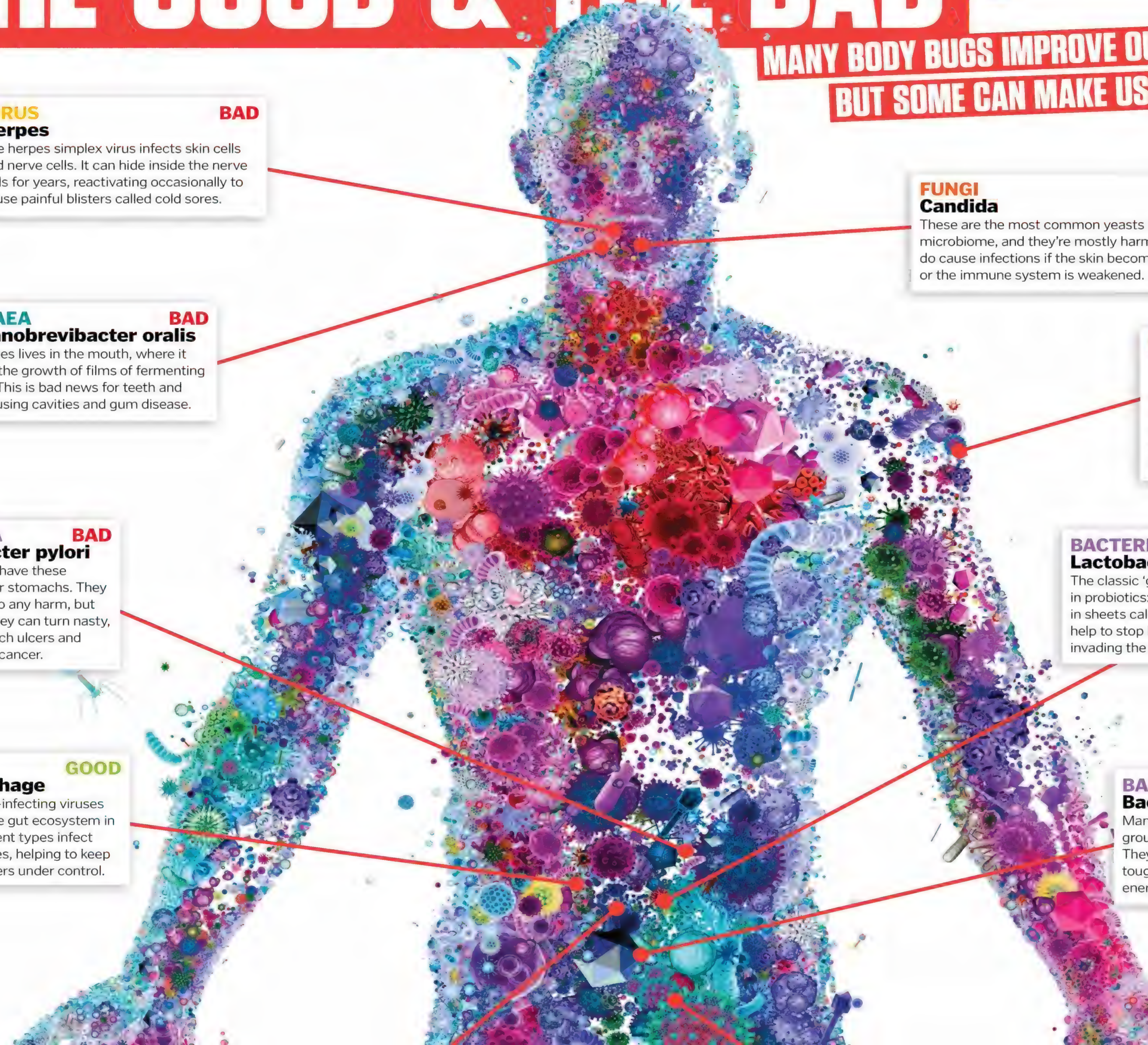
THE GOOD & THE BAD

MANY BODY BUGS IMPROVE OUR HEALTH, BUT SOME CAN MAKE US SICK

BACTERIA
FUNGI
ARCHAEA
VIRUS



VIRUS — **BAD**
Herpes
The herpes simplex virus infects skin cells and nerve cells. It can hide inside the nerve cells for years, reactivating occasionally to cause painful blisters called cold sores.

FUNGI — **BAD**
Candida
These are the most common yeasts in the human microbiome, and they're mostly harmless, but they do cause infections if the skin becomes damaged or the immune system is weakened.

ARCHAEA — **BAD**
Methanobrevibacter oralis
This species lives in the mouth, where it supports the growth of films of fermenting bacteria. This is bad news for teeth and gums, causing cavities and gum disease.

FUNGI — **GOOD**
Trichosporon
These yeasts live on healthy skin and don't usually cause any trouble. Occasionally, in wet conditions, they can colonise the hair, forming harmless white lumps called piedra.

BACTERIA — **BAD**
Helicobacter pylori
Lots of people have these bacteria in their stomachs. They don't usually do any harm, but occasionally they can turn nasty, causing stomach ulcers and even stomach cancer.

BACTERIA — **GOOD**
Lactobacilli
The classic 'good bacteria' found in probiotics: they grow together in sheets called biofilms, which help to stop bad bacteria invading the gut.

VIRUS — **GOOD**
Bacteriophage
These bacteria-infecting viruses help to keep the gut ecosystem in balance. Different types infect different species, helping to keep bacteria numbers under control.

BACTERIA — **GOOD**
Bacteroides
Many of our gut microbes belong to a group of species called Bacteroides. They help us out by turning tough-to-digest carbohydrates into energy-packed fatty acids.

ARCHAEA **GOOD**

Methanobrevibacter smithii

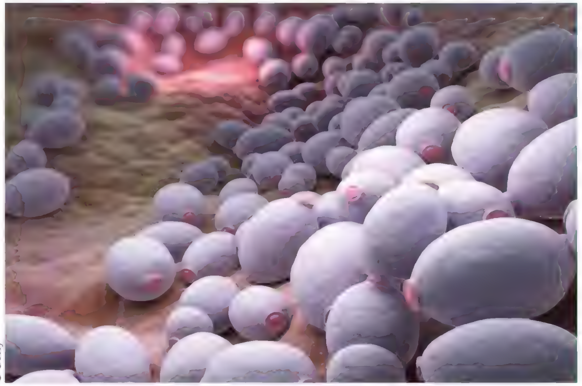
This species boosts digestion by turning hydrogen into methane. This helps good gut bacteria to make more energy, but can cause smelly wind.

VIRUS **GOOD**

Endogenous retroviruses

Known as 'fossil viruses', these are genes left over by ancient viral infections. Some now form vital parts of our biology, including helping to build the placenta.

"The ecosystem in our intestines is essential for our survival"



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These little ball-shaped bugs are the skin-infecting yeast, *Candida albicans*

© Getty

Your intestines are full of bifidobacteria. These tiny bugs help to digest your food

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Ancient mouth microbes revealed

Thousands of years ago, Neolithic hunter-gatherers made sticky black chewing gum from birch tree tar. As they chewed, their saliva mixed with the gum, leaving behind traces of DNA. In 2019, scientists found a piece of this ancient gum, preserved for 5,700 years beneath the sand in Denmark. Human DNA in the sample revealed that the gum-chewer was a woman with dark skin, brown hair and blue eyes. Plant and animal DNA revealed that she'd recently eaten duck and hazelnuts, and bacterial DNA revealed that her mouth was full of similar bacteria to ours, including bugs that can cause gum disease.

© Getty

Chewed gum carries the DNA signatures of you, your food and your mouth microbes

MICROBIOME BY NUMBERS

10:1

Viruses outnumber bacteria 10:1 in the intestines

1,000

1,000 species of bacteria can live in human intestines

0.1MM

Human eyes can't see anything smaller than 0.1mm

30%

of people have *Staphylococcus aureus* living in their noses

0.01MM

Body-infecting yeasts are smaller than 0.01mm

2KG

The weight of microbes in your gut

600

More than 600 species can live in the airways

40%

of people have *Helicobacter pylori* living in their stomach

0.002MM

Most gut bacteria are smaller than 0.002mm

23,000

The human genome has only 23,000 genes

1,000,000

The human microbiome has more than 1,000,000 genes

10%

of your gut microbes are bifidobacteria

1,000

1,000 species can live on the skin

95%

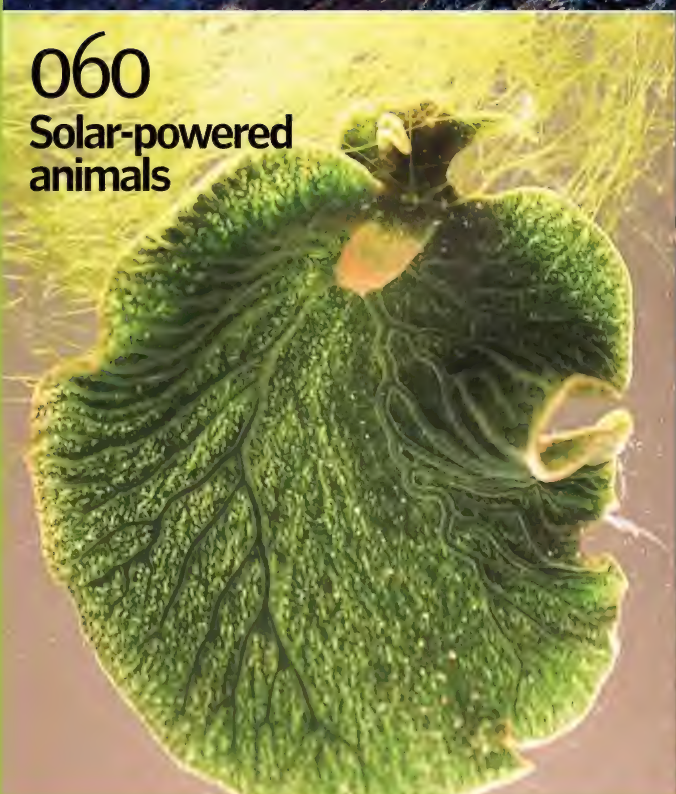
of your body bugs live in your intestines

25

25 species can live in the stomach

ENVIRONMENT

040
Exploring the Himalayas



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Solar-powered animals

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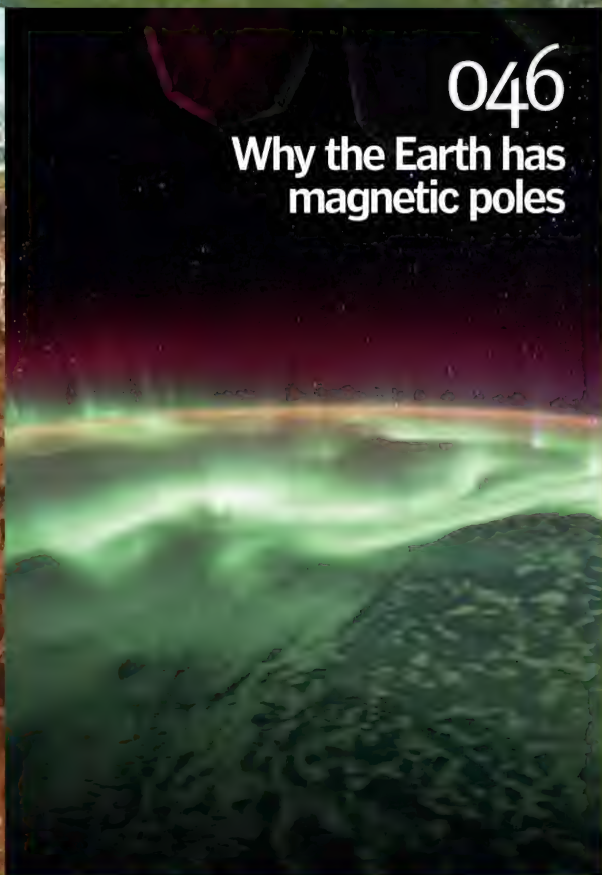
How do birds fly?



EXPLORING THE HIMALAYAS

How one collision created a diverse land of culture, ecology and the world's tallest point

Words by **Ailsa Harvey**

Covering close to 600,000 square kilometres, the Himalayas are a mountaineer's playground. With over 50 mountains exceeding 7,000 metres and home to ten of the world's 14 highest peaks, the choice and range of required skill sets provides a challenge for explorers of all abilities.

Some of the earliest people to venture into the Himalayas were traders and pilgrims. Like most who have visited the area, pilgrims took to the mountains in search of a test. Through religion, they saw the Himalayas as an environment of physical extremes. They believed that the more testing their pilgrimage was, the more worthy they became of salvation. And what place is more testing than the Himalayas?

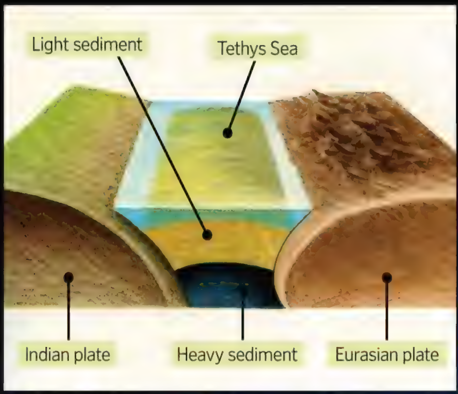
Divided into three geological zones – the Outer Himalayas, the Middle Himalayas and the Great Himalayas – the environment ranges from the tropics down below to the jagged peaks that cut into the clouds. Passing through five countries – India, Pakistan, China, Bhutan and Nepal – it is no wonder the Himalayas are so varied. The further down you explore into valleys shadowed by steep slopes, the more variety in life you'll find – from the mountain-dwelling creatures who have adapted to suit this unique environment to the settlements and villages below the snow line who live off the resources from the mountains.

Initially it was believed that the earliest human inhabitants lived in the area no earlier than 5,200 years ago. Now, however, evidence in the form of ancient footprints solidified into mud dates the start of mountain life between 7,400 and 12,600 years ago. While the high-altitude areas of the Himalayas are not the easiest places to live, at this time the region would have been more humid, and agriculture could have been better supported higher up in the mountains.

The climate continues to change to this day, shaping a new version of the Himalayas. With growing concern over the implications of global warming, nations surrounding the mountain range are working together to protect the land they not only admire, but depend on. More than 240 million people have made the peaks and crags their home, and amid the climate crisis are seeing some of the most dramatic impacts take a toll on it.

HOW THE HIMALAYAS FORMED

As an isolated island, 200 million years ago India started drifting in the direction of Asia. Millions of years later, its collision with the mainland would create the world's highest mountain range



1 60 million years ago
As India inched further north, the width of the Tethys Sea gradually decreased. When India reached Eurasia, a landmass of similar rock density, the sediment making up the Earth's crust felt an extreme force from both directions. Initially, because the two continental plates were of equal buoyancy, neither could push the other down underneath itself in a process called subduction. As the sea became narrower and pressure rose, the only option in relieving it was to throw the crust between them upwards.

2 40 million years ago
The heavier sediment at the floor of the Tethys Sea was able to force its way underneath the Eurasian plate over time. Meanwhile, India continued to push the base of the Eurasian plate, settling in position underneath it. The Indian plate kept moving, but slowed to half its original speed following the collision.

The king of the Himalayas

As the world's highest mountain, Mount Everest is at the top of many extreme explorers' lists. Others leave the peak of danger and uncertainty to the most daring and elite. As an attraction bringing hoards of tourists to the Himalayas, only a few make it to the summit. Every year since 1990, at least one person has died in pursuit of reaching its highest point.

The first official attempt to climb Mount Everest was in 1921 by a British team, but it wasn't until 29 May 1953 that the first mountaineers made it to the top – 8,848 metres above sea level.

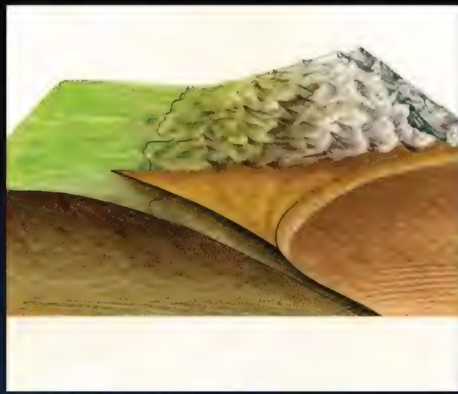
Tenzing Norgay and Edmund Hillary climbed all the way up with the knowledge of the mountain's history of taking life. Of the few who had tried before them, many had not returned, but their adrenaline and desire to succeed overcame their fears. Since then about 5,000 people have climbed Mount Everest, and more than 300 people have died trying.

While a stunning spectacle looming over Tibet and Nepal, history tells of the extreme conditions on Everest. A combination of the human body's inability to cope with such altitudes, freezing conditions and the length of time exposed to the elements over the distance travelled means there's an area of the Himalayas only the elite can successfully experience. Even then, the unpredictability of rock and ice falls, avalanches and earthquakes make for the powerful and unforgiving personality that is Mount Everest.

Tenzing Norgay and Edmund Hillary photographed after climbing Everest

3 20 million years ago
After the Tethys' sea floor was forced downwards under the plates, only some heavy sediment remained. This sediment, wedged between the colliding plates, started to crumple upwards. This creased land was the early creation of the Himalayas, in place of the sea's disappearing water. Tibet, part of the Eurasian plate, began to rise with it.

4 Today
19-kilometres deep underneath the surface of the Himalayas, the Indian plate is still pushing northwards under the Eurasian plate. As the two plates continue to press against each other, the forces are pushing the Himalayan mountains marginally higher as every year passes.



5 10 million years from now
If the plates continue to move over each other at the current rate, Nepal's opposite borders will overlap each other, and the area where the country once was will no longer line up. As Nepal ceases to exist, the Himalayas – at the tallest they will have ever been – will be located near the Indian border.

5 FACTS ABOUT HIMALAYAN LIVING

1 Himalayan inhabitants
50 million people live among the mountains, with a further 450 million living along the base.

2 Extra land
In a process called 'terracing', people often make steps in the mountainside to increase flat land area used for growing crops.

3 Dung patties
In some villages, yak dung is dried into patties and used as fuel for fires.

4 Nature appreciation
Today and historically, many communities living in the Himalayan mountains and foothills view their unique surroundings as their protector and provider of all life. Many living in harsh environments are also dependant on nature and greatly respect it.

5 Thriving tourism
Over 700,000 tourists travel to the Himalayas every year. This 60 per cent increase since the 1990s has provided locals with more jobs, but is also negatively impacting the environment through pollution and deforestation.

Changing with the climate

Through studies of wildlife across the Himalayan landscape, it has been discovered that plants are surviving higher up the mountains than they were just 25 years ago. Between 5,000 and 5,500 metres, plants are testing the boundaries of where they can grow and are moving up the hills. In addition to plants, one of the most noticeable changes from global warming is the impact on snow and surface ice. As the planet continues to rise in temperature, snow and glacial ice will melt more rapidly and provide more areas suitable for plants to grow. This extra water will change what the area looks like, as well as the lives of those living in the foothills. Currently scientists are looking into the possibility of increased plant life acting as a catalyst in the warming of the Himalayas. Plants absorb heat and could change the way it is distributed across the land.

Melting of Himalayan glaciers has doubled in the last 20 years

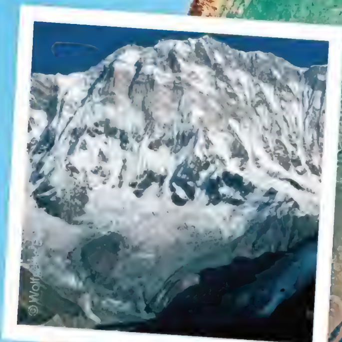
Everest South Base Camp, where many prepare for their climb, is 5,364 metres above sea level

TOP 10 HIGHEST

Not only the highest in the Himalayas, but also the world: these mountains make up all but four of the planet's 8,000-metre-plus peaks

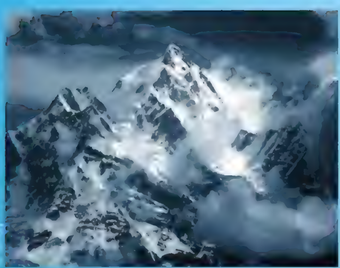
10 Annapurna I East, 8,026m

This mountain is the tallest in the Annapurna range and the tenth-tallest peak in the world. Annapurna is named after a Hindu goddess, whose name means 'filled with food'. With the huge mountain creating runoff water for much of the land below, it provides the ideal conditions for crops and food to be grown for the surrounding communities. The Annapurna mountain range has been a conservation area since 1985, becoming the largest protected area in Nepal.



9 Nanga Parbat, 8,126m

The name means 'naked mountain' in Urdu, due to the sides being so steep that snow often doesn't settle on much of it. Relatively young, the mountain is only 1 or 2 million years old. After the 31st mountain climber died attempting to reach the top, many in the community referred to it as the 'Killer Mountain'. This nickname has remained. The first attempt was an unsuccessful one, as in 1895 Alfred Mummery and his group set off into the unknown, never to return.

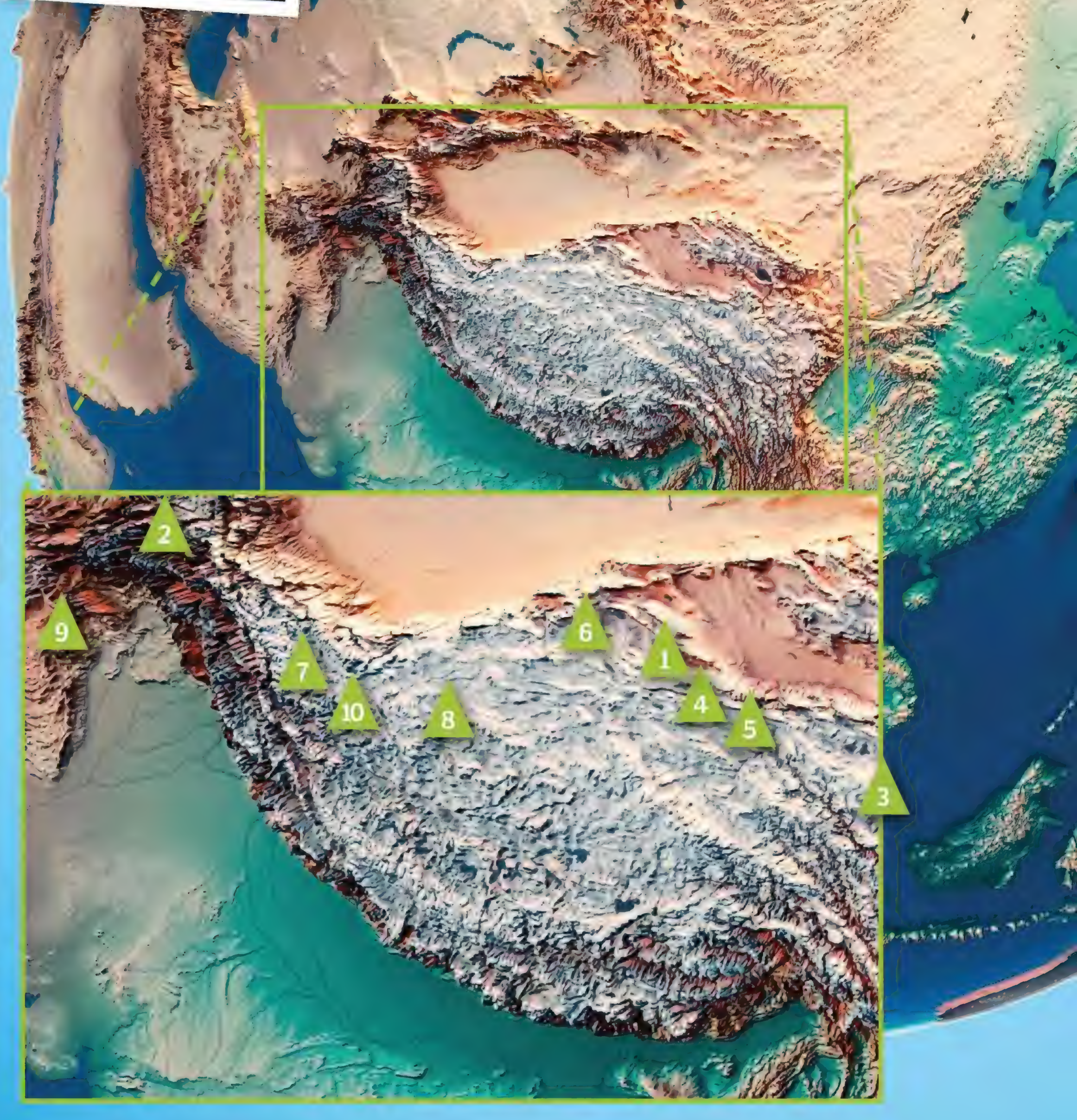


8 Manaslu, 8,163m

The area of Manaslu – meaning 'the mountain of spirit' – covers six climate zones, from tropical to alpine and arctic. Situated in the Gorkha District of Nepal, the eighth-tallest mountain in the world has long ridges and valley glaciers. Because of the first ascent being completed by Toshio Imanishi and Gyalzen Norbu of Japan in 1956, some claim that the peak belongs to Japan.

7 Dhaulagiri, 8,167m

When discovered in 1808, Dhaulagiri was thought to be the world's highest mountain. While it is actually the seventh tallest, it remains impressive and unique. Soaring 7,000 metres over the Kali Gandaki Gorge and stretching across 30 kilometres in length, Dhaulagiri's main crest is home to several peaks. Of these, four reach heights above 7,600 metres.



6 Cho Oyu, 8,188m

Found on the border between Nepal and Tibet, 32 kilometres north of Everest, sits Cho Oyu. While mighty in size, this mountain is relatively tame and is considered to be the safest of all the 8,000-metre peaks. With its fatality rate considerably low at one per cent, the climb is the most popular of the ten. The ascent on the north-facing side is deemed a gentle slope, which doesn't require too much technical skill. However, high fitness is crucial. In addition, avalanches are much less common.

5 Makalu, 8,485m

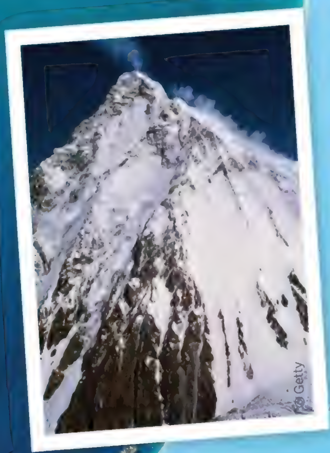
Taking fifth in the competition to be the world's tallest mountain is Makalu. Shaped like a four-sided pyramid, the mountain stands alone on the Tibetan-Nepalese border. The extreme and diverse terrain makes this mountain particularly dangerous. It's steep, and near the top rock climbing skills are required to move past the final ridge.

4 Lhotse, 8,516m

When the top of Lhotse was first reached in 1956, it was merely a warm up to the main event; the climbers were using it as an alternative route to get to Everest. However, climbing this mountain is no easy feat. The fourth-highest mountain has two smaller peaks surrounding its main summit: Lhotse Shar to the east and Nuptse to the west. The west face near the top of this mammoth mountain has been claimed by many to be more challenging than Everest itself. Standing as a vast wall of blue glacial ice, choice of foot placement in this section can be the difference between making the summit or plummeting to your death.

3 Kangchenjunga, 8,586m

In the shape of a large cross, Kangchenjunga reaches outwards to the north, east, south and west. Structurally the mountain has five peaks, giving it its translated name of 'the five treasures of the high snow'. Consisting of rock up to a billion years old, the mountain has sacred value to many local Buddhists. Each peak is said to represent the five gifts from god: gold, silver, gems, grains and holy books. In the year 2000, the Indian state of Sikkim banned visitors from climbing the peak out of respect.



2 K2, 8,611m

Also referred to as Mount Godwin-Austen after its early explorer Henry Godwin-Austen, this mountain resides in the Karakoram mountain range on the border of China and Pakistan. Around a quarter of the people who have attempted to get to its peak have died trying, earning it the nickname of 'Savage Mountain'.

For a year the mountain was incorrectly regarded as the world's tallest before explorers realised it actually measured more than 200 metres below Everest. While second highest in terms of height above sea level, it is classed as the 22nd most prominent mountain. Its point rises over 4,000 metres above the ground below.

1 Everest, 8,848m

Reaching the top of Everest means reaching the world's highest point, and that point is still getting around six millimetres taller every year. Estimated to be between 50 and 60 million years old, the plates below it continue to move. This instability adds to the unpredictable nature of Earth's mightiest mountain, causing tremors, avalanches and earthquakes.

For humans the heights of Everest can be unforgiving. With a third of the air pressure found at sea level, oxygen deprivation is the greatest risk to life. Reaching minus 40 degrees Celsius in winter months, frostbite is another deadly prospect. What is it like to reach the top of the world? Most people who climb the mountain use one of two main routes, but there are 17 routes to take. The top of the mountain consists of a small, snowy dome, allowing only a handful of people to truly be on Earth's summit at one time.

ANIMALS OF THE HIMALAYAS

Yak

Widespread across the Himalayan region, the yak is most similar to the cow or buffalo. Today the animal is mainly domesticated, and their strength is often used as a form of transport for goods across the mountainous land. Covered in long hair, yaks are adapted to live in cold climates at high altitudes.

Snow leopard

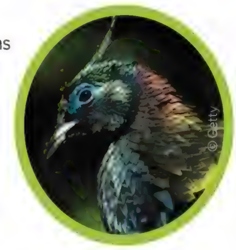
These leopards are accustomed to the snowy regions of the Himalayas. If you can see past their camouflaged coat, they can be spotted high up in the mountains. One of their key characteristics helping them move swiftly on the area's uneven ground is their long, thick tail, used for balance.

Red panda

The distinctive red panda is most common in the eastern areas of the Himalayas, such as Nepal, China and Bhutan. As the majority of their lives are spent climbing tree branches, this panda is found lower in the Himalayas where tree life is supported.

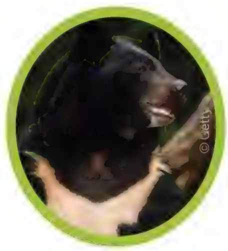
Himalayan monal

The Himalayan monal, also known as the danphe, is Nepal's national bird. Vibrant in their rainbow feather display, these animals are like a cross between a pheasant and a peacock. Usually the birds can be seen among the trees and the shrubland between 2,100 to 4,500 metres high.



Himalayan black bear

The location of this rare Asian black bear subspecies changes with the season. During the summer months they can adventure to heights of 3,000 metres, but come winter they remain at half this height in the more comfortable tropical areas of Tibet, Nepal, China and India.



Himalayan tahr

The tahr have adapted to the steep rock faces of the Himalayas. Their dense coats change thickness with the temperature and their flexible hooves make them better climbers than similarly built goats. Unfortunately these animals have suffered a loss in numbers due to hunting and habitat loss from increased human population.

Why the Earth has magnetic poles

Extraordinary geological goings-on in the planet's chaotic core power its polarity

Words by **Jack Parsons**

When a compass points north, what's guiding it? The answer is the magnetic north pole. The compass needle is attracted by this awesome power in the Arctic. This is different from the place we call the North Pole though. It's the tip of a vast bubble of energy that surrounds the whole planet.

While Earth's magnetic field reaches into outer space, it begins about 2,900 kilometres beneath our feet. The planet's outer core is a scorching sea of molten iron and nickel. This is always churning, with liquid metal rising as it heats, then cooling and sinking. The planet's rotation also causes swirling whirlpools to form. As this liquid metal is conductive, this constant motion acts as a dynamo. It generates electricity, producing a magnetic field.

Like an everyday bar magnet, Earth's magnetism concentrates at two ends: one in the far north, and the other south. While the force is strongest at these poles, the invisible field fans out in every direction between these two points, so it's all around us.

Geological evidence suggests that the 'geodynamo' that powers Earth's magnetic field began at least 3,450 million years ago. When the hellishly hot core eventually cools and hardens, the magnetism will fade away – like it did on Mars long ago. While that's billions of years away from happening on Earth, that doesn't mean the magnetic field is stable. Even slight fluctuations in the core's temperature or fluid flows can have very dramatic effects.

First off, it can make the poles move. The magnetic north is currently wandering from Canada towards Siberia – and it's gaining momentum. While it once shifted an average of 15 kilometres a year, since the mid-1990s it's been moving at 55 kilometres a year. The exact cause is uncertain, but a high-speed jet of liquid iron may be to blame.

The strength of the magnetic field also varies, waxing and waning in different parts of the world each year. There are signs that it's been weakening worldwide for 160 years, possibly due to dense rock under Africa interfering with the core.

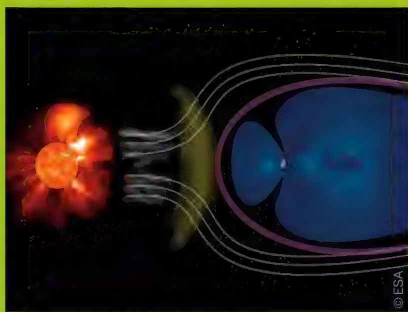
Most incredibly of all, a quirk in the core's chemistry can even make the poles reverse. It's actually happened hundreds of times before – though not for 780,000 years. When it takes place it's not quick either, with the shift taking thousands of years. Future generations might be asking why their compasses always point south instead.

The planet's protective shield

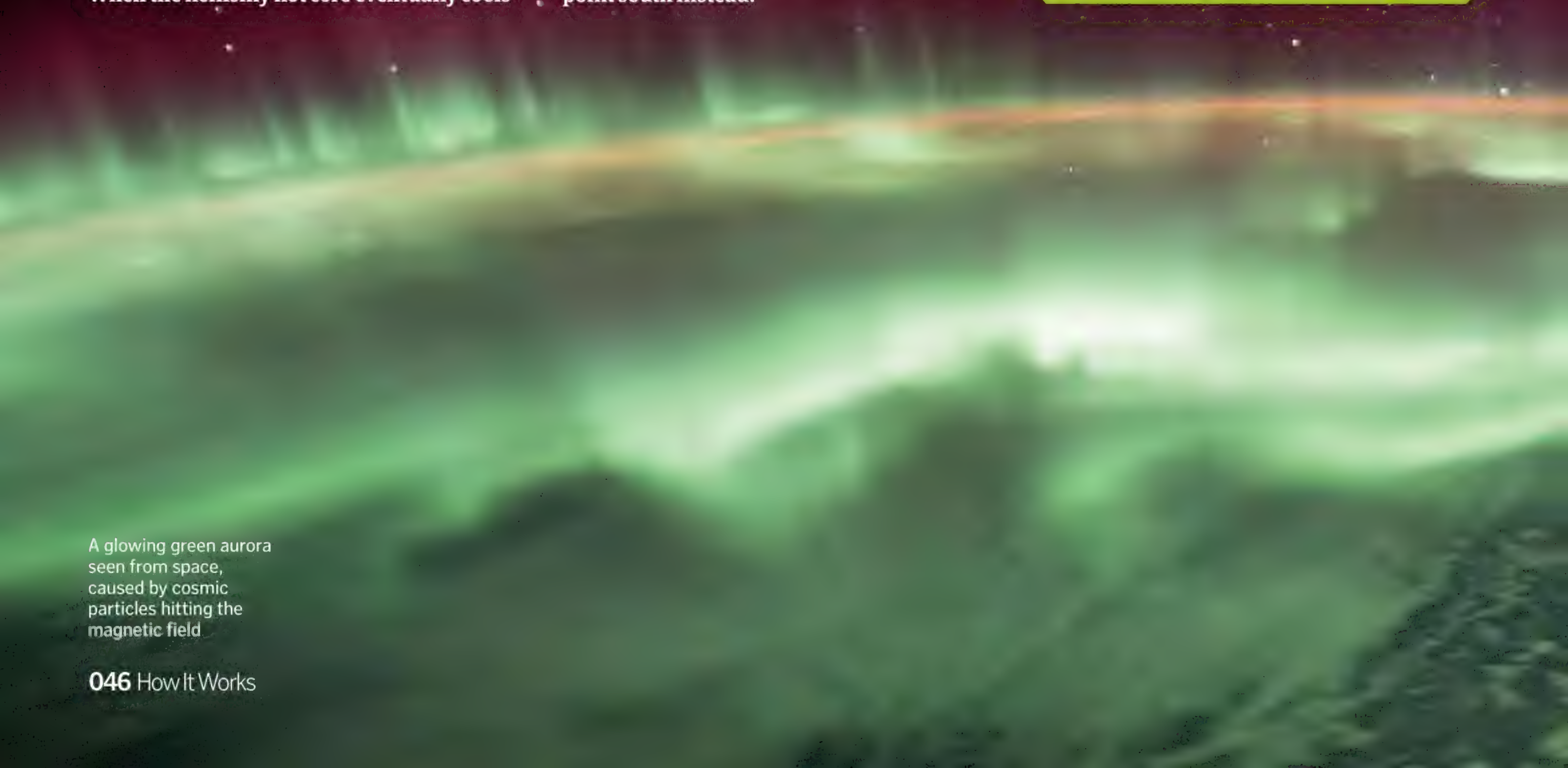
Earth's magnetic field protects life on Earth from the plasma and particles that constantly spew from the Sun. Without this barrier the 'solar wind' would ravage our atmosphere, starting with the ozone layer that keeps out ultraviolet radiation.

Instead, the magnetic field redirects the charged particles around the planet so that they stream beyond it. But this gust of wind still distorts our magnetic field, compressing the magnetic lines close together on the dayside of Earth and stretching them out into space on the nightside.

Sometimes the Sun releases a larger burst, known as a 'solar storm'. This can overwhelm our protective barrier, but magnetic field lines still funnel these invasive particles to the poles. Here they react with the molecules in the air, so oxygen glows yellow and green. Nitrogen gives off red, violet and occasionally blue. This is the dazzling natural light show we call the aurora.



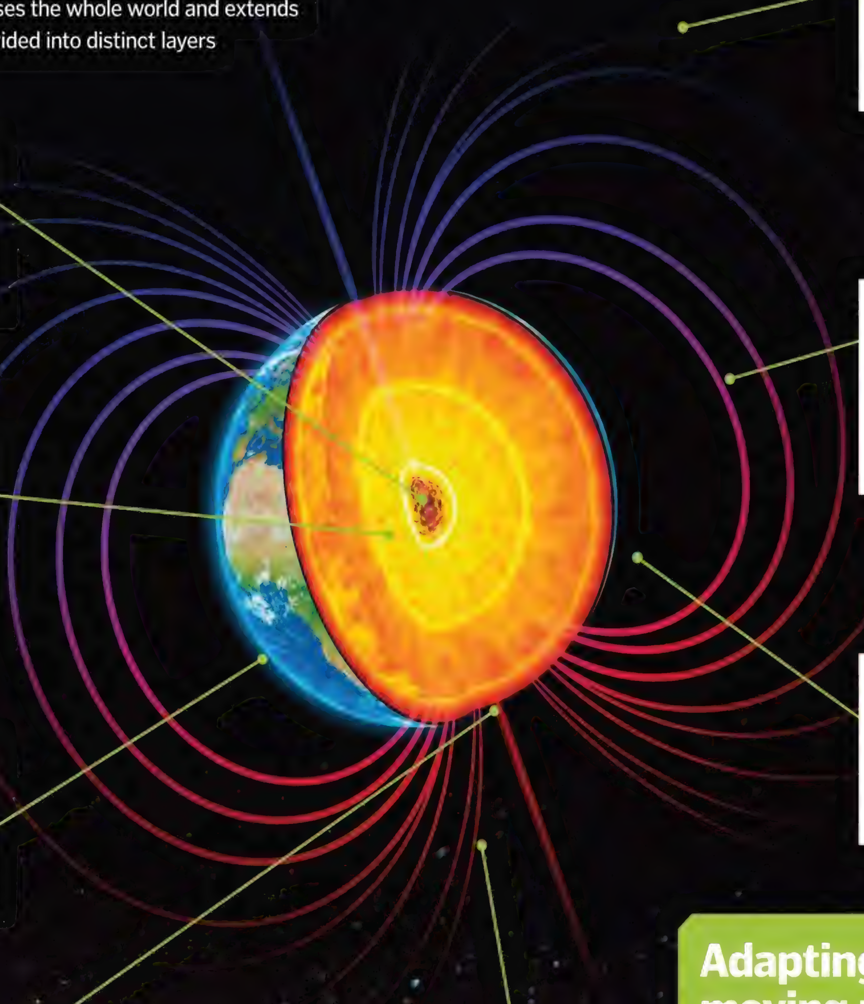
The magnetic field deflects the constant stream of dangerous particles from the Sun



A glowing green aurora seen from space, caused by cosmic particles hitting the magnetic field

Explore the magnetosphere

The magnetic field encompasses the whole world and extends into space, where it can be divided into distinct layers



The inner core
Earth's heart is two-thirds the size of the Moon. Temperatures here can reach up to 5,500 Celsius, but the crushing pressure prevents the iron from melting.

Liquid-metal layer
The outer core is about 2,200 kilometres thick. This sea of molten iron-nickel alloy is heated by the inner core and creates the magnetic field as it's grilled.

The motion of the ocean
While the core is the main source of Earth's magnetism, minerals in the crust and tidal movements also generate less powerful fields.

Polar opposites
Like a simple bar magnet, the Earth's magnetic field is a dipole – meaning it has two poles. One's in the north, the other is in the south.

The magnetopause
Several hundred kilometres in the air, this is where the solar wind and our magnetic field collide.

The bow shock
The furthest reaches of the magnetosphere act like a hump in the road, forcing the solar wind – often travelling at 500 kilometres per second – to reduce its speed.

The magnetotail
While the dayside of the magnetosphere is battered by solar wind, the nightside forms a long tail that can stretch hundreds of times the Earth radius, beyond the Moon's orbit at 60 Earth radii.

The ionosphere
Starting about 50 kilometres above the surface, this region is full of atoms that have been stripped of their electrons by the solar wind and cosmic rays. The aurora appears in its upper layers.

Adapting to a moving pole

The magnetic north pole's speedy drift has left authorities scrambling. Last year they had to update the World Magnetic Model – which is used by military forces and GPS systems on smartphones – a year ahead of schedule. If they hadn't, journeys around the Arctic region could have been disrupted.

Many species – including bees, pigeons and turtles – also use magnetism to navigate. The pole's sudden shift might throw off their bearings, so they can't find their breeding grounds or hunting spots. But, like us, the animal kingdom will adapt eventually.

We've been tracking the magnetic north pole's movements for over a century

WHAT IS PERMAFROST?

This permanently frozen ground in Arctic regions has major consequences for global warming

Words by **Amy Grisdale**

Almost 15 million square kilometres of Earth's ground is frozen solid. Permafrost covers nearly as much of the planet as Russia does. Soil, silt or clay must stay at zero degrees Celsius or lower for two years to qualify as permafrost, and it's over one kilometre thick in parts of Siberia. Some areas of permafrost are so laden with ice that it's twice the weight of the soil around it. In Alaska subterranean blocks of ice reach 35 metres deep and span 500 kilometres.

These vast frozen areas are remnants of the last ice age. They formed over thousands of years and have survived until the present day. Each summer the top layer of the frozen soil could thaw enough for plants to grow. As time went on, a lot of organic matter found its way into the soil. Eventually vegetation and animal

Previously frozen ground implodes when it isn't held together by ice any more

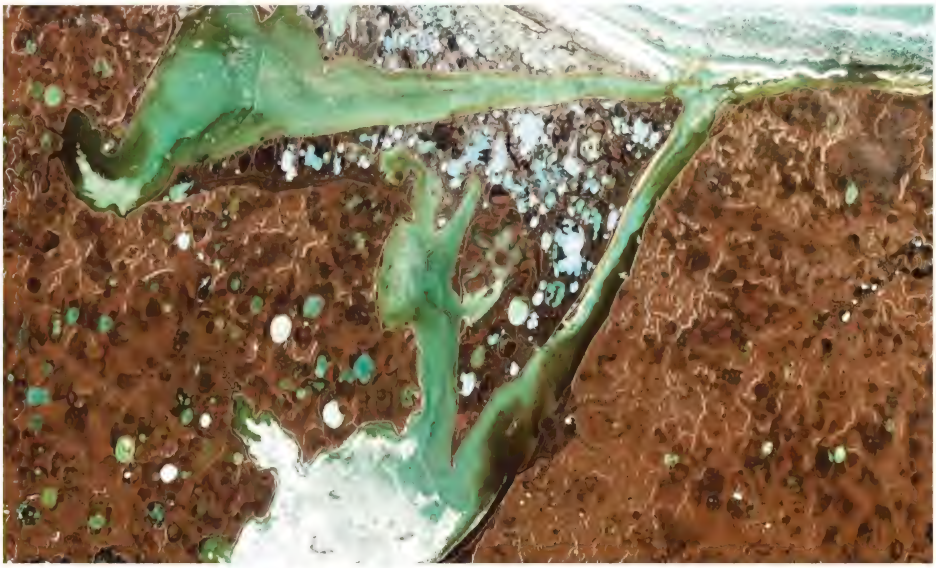
Prehistoric ivory

Because permafrost is so good at preserving animal tissue, there are thousands of mammoth tusks trapped underground. People visit Siberia to unearth these tusks – 90 per cent of which end up in China. Carved ivory ornaments are a status symbol, but elephant ivory is illegal in China. Mammoth ivory is considered an ethical source of ivory so the demand for it is sky high. A 65-kilogram tusk fetches £23,000.

But not only is the scientific community losing potential discoveries to the ivory trade; the permafrost itself is suffering. Mammoth hunters blast the ice with water and excavate cavernous tunnels, causing unnecessary damage. Sludge from the melted ground also runs into nearby rivers, making the water dirty and more dangerous to navigate.

The number of tusks still encased in permafrost seems to have diminished significantly, and hunters are struggling to find valuable prehistoric tusks now that they are in low supply.

Polar bears are at great risk from tusk hunters and are usually shot on sight to avoid conflict



© NASA

A satellite image of the north Siberia coast, showing thermokarst lakes, which are pockets of permafrost meltwater

remains were buried in the permafrost, where they couldn't decay. Intact remains of extinct megafauna are found in permafrost to this day in near-pristine condition.

All of this tissue would rot if global temperatures got high enough to melt the permafrost that's keeping it preserved. The bacteria that feed on decomposing material release greenhouse gases. If the planet gets hot enough, melting permafrost could accelerate climate change.

Permafrost prevents the ground from absorbing water, creating wetlands and lakes that normal rainfall couldn't sustain. People and wildlife rely on these environments to survive, and the loss of permafrost would have an enormous impact. If subterranean ice were to melt, the land would change drastically. Some areas would dry out, while others would get wetter. The chemical makeup of the water would change and the ground would become irregular. The new landscape could alter the course of rivers, affecting fish and wildlife.

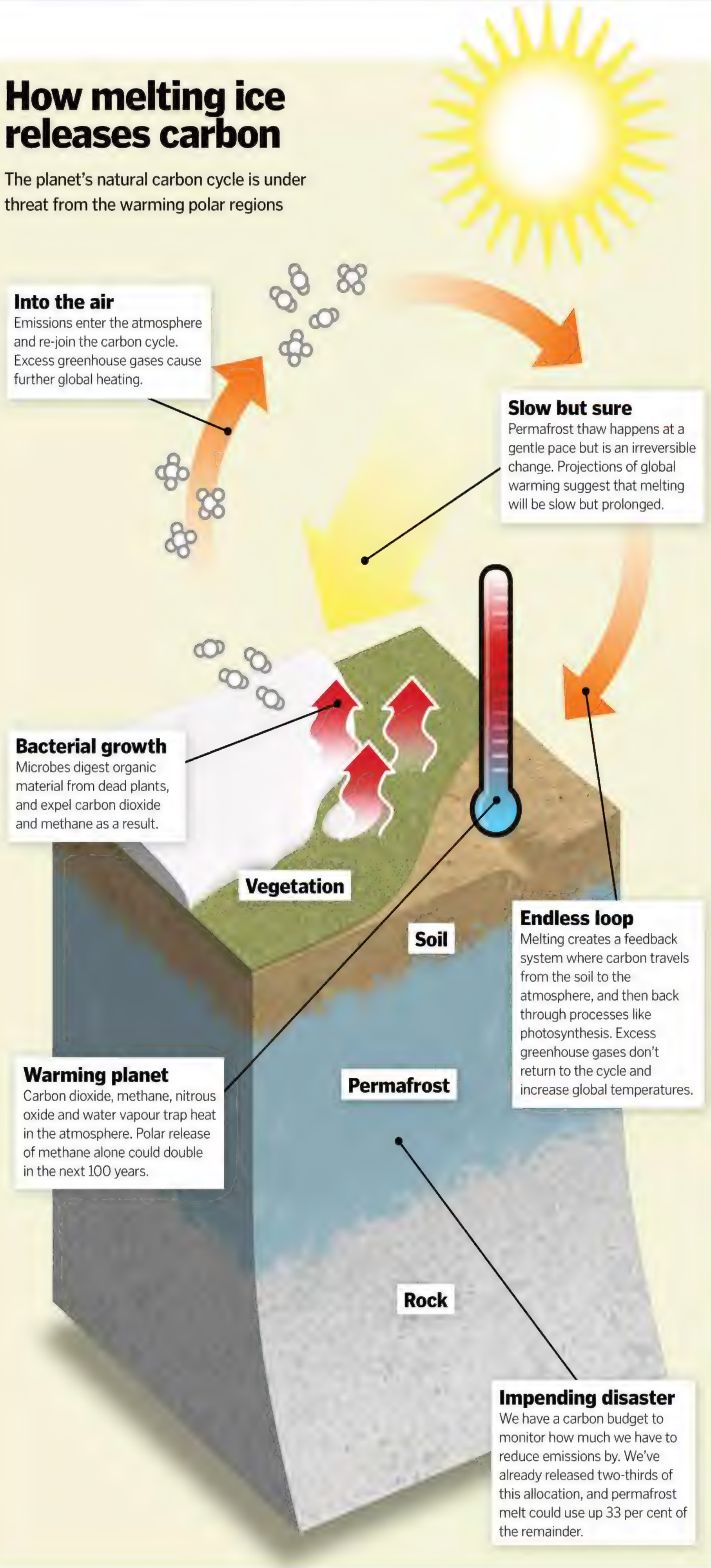
Unfortunately permafrost is beginning to melt thanks to our changing climate. While the local

> "Polar release of methane alone could double in the next 100 years"

About 60 per cent of Russian land contains permafrost, and the country's scientists study it closely, measuring how it changes

How melting ice releases carbon

The planet's natural carbon cycle is under threat from the warming polar regions



Into the air
Emissions enter the atmosphere and re-join the carbon cycle. Excess greenhouse gases cause further global heating.

Slow but sure
Permafrost thaw happens at a gentle pace but is an irreversible change. Projections of global warming suggest that melting will be slow but prolonged.

Bacterial growth
Microbes digest organic material from dead plants, and expel carbon dioxide and methane as a result.

Endless loop
Melting creates a feedback system where carbon travels from the soil to the atmosphere, and then back through processes like photosynthesis. Excess greenhouse gases don't return to the cycle and increase global temperatures.

Warming planet
Carbon dioxide, methane, nitrous oxide and water vapour trap heat in the atmosphere. Polar release of methane alone could double in the next 100 years.

Impending disaster
We have a carbon budget to monitor how much we have to reduce emissions by. We've already released two-thirds of this allocation, and permafrost melt could use up 33 per cent of the remainder.

Crumbling tundra

Surplus melted water creates fragile soil peppered with marshy potholes. In some cases huge divots appear, like the Batagaika crater in northeast Siberia. It's the biggest of its kind, stretching for more than a kilometre. It's still growing too. The cavity has been known to advance by 30 metres in years with warm weather. The giant hole first appeared after a stint of logging in the 1960s. The once-frozen ground was heated by exposure to direct sunlight and eventually caved in. Over the years it has been carved deeper by flooding, and more land collapse could be ahead as the crater advances towards a nearby valley. On the positive side, the opening of this cavernous pit has given scientists a new insight into the past. It has revealed 200,000 years of history of a planet that has undergone extreme temperature fluctuations for billions of years. Learning about climate change in this recent past could give us a better understanding of what the Earth is experiencing today.


The Batagaika crater started forming after logging activity exposed the frozen ground to direct sunlight


The crater grows every year, getting increasingly wide and deep


The crater is revealing thousands of years of history that's been buried and frozen underground

Permafrost hotspots

This Alaskan home was destroyed by climate change-fuelled erosion. The entire island may eventually be evacuated.

Melting permafrost on Herschel Island is risking cultural sites there. The region is experiencing the greatest rise in annual temperatures in the world.

Svalbard's 'doomsday' vault contains seeds to conserve the planet after a catastrophe, but melting permafrost could put the Earth's emergency supplies at risk.

Exposed permafrost in Norway melting. Melting permafrost helps release carbon dioxide and methane into the atmosphere.

Permafrost is essential to the maintenance of lakes. Regions with permafrost will be transformed as the world heats up.

"We have little information about their physiology and metabolic demands. We can't be sure what will happen if they begin to feast on all the carbon-filled organic matter frozen beneath them"

Coastal erosion at Alaska's Teshekpuk Lake shows the depth of its permafrost layer

area will be threatened, there may also be consequences for the entire planet. The Arctic takes up more carbon than it makes, so we call it a carbon sink. The plants that grow throughout the continent suck up carbon from the air in photosynthesis. If the Arctic gets hot enough to thaw permafrost, it could become a source of greenhouse gases. This could be the point of no return for the planet. Extra hydrocarbon release would lead to increased warming, which in turn would cause more hydrocarbon expulsion from melting ice. As much as 1.4 trillion tons of these gases could be locked up in permafrost.

Half of the organic material buried in the Earth's soil is frozen. A temperature increase of just a few degrees could melt permafrost and allow the plant and animal remains to break down. Earth has warmed up by 0.8 degrees Celsius since 1880 - and estimates suggest that a temperature increase of just one degree Celsius could jeopardise more than a quarter of the planet's permafrost.

Frozen layers examined

The surface of permafrost is called the active layer. This bit at the top thaws and freezes again every year. The topsoil can be a mere dusting on the ground or reach five metres in depth, and is rich in bacteria. One gram of soil might hold more than 1 billion microbes. Most of these microscopic organisms cannot be grown in lab conditions, and we have little information about their physiology and metabolic demands. We can't be sure what will happen if they begin to feast on all the carbon-filled organic matter frozen beneath them.

Ice wedges are described as 'massive' when their frozen water content reaches 250 per cent. These are the result of existing liquid reservoirs under the ground or an amalgamation of water from precipitation and surface flow. As temperatures rise, less and less of the permafrost survives to the next winter. The active layer is getting thicker as the ice beneath retreats, and the coldest areas of permafrost are heating the quickest.

The ground transitions from a fertile upper layer to solid ice buried underneath

Exposed chunks of ice overhang a small pond in Spitsbergen, Svalbard in Norway

How do birds fly?

Their specialised frame is built for flight, from their bone structure to the way they breathe

If there's one thing humans tend to envy about other members of the animal kingdom, it's flight. Our natural capabilities limit us to only land and water, but for birds the sky is literally the limit. How is it that they can lift into the air with seemingly effortless movements?

Almost every part of a bird's body has evolved to maximise flying potential in some way. Relative to their size, birds' hearts are bigger and more powerful than those of most mammals, to keep essential flight muscles working. Birds also have huge breast bones, providing more space for flight muscle attachment.

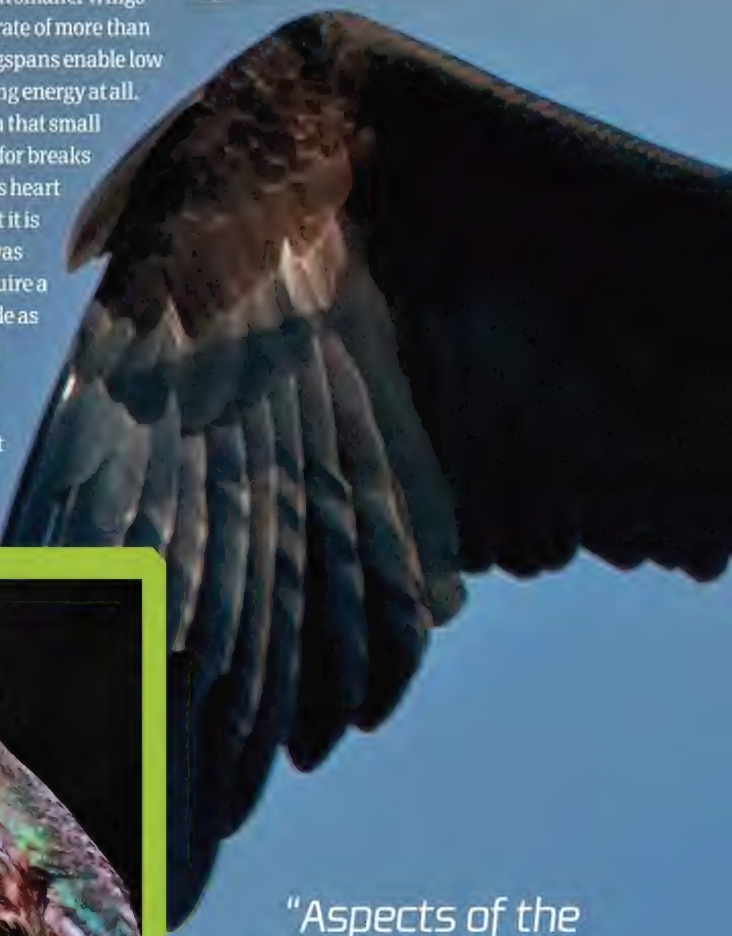
Hollow bones enable oxygen to travel more freely around the body but still have the strength to tackle the strains of flight. Some birds have a skeleton that's even lighter than their feathers.

Birds' feathers, made from keratin, evolved from those of dinosaurs to provide a light surface that can push against the air to facilitate flight.

There are around 10,000 bird species, ranging in size from seven centimetres to over 1.8 metres, so the flying method and build of these birds can vary massively. Often, birds with smaller wings can hover by beating them at a rate of more than 40 times per second. Large wingspans enable low gliding, so birds exert no flapping energy at all.

However, studies have shown that small birds also glide through the air for breaks between flapping. A small bird's heart rate when gliding is half of what it is when it's flapping its wings. It was discovered that these birds require a similar amount of energy to glide as they do to rest in their nests. In comparison, when large birds soar above the wind, their energy expenditure was at least 30 per cent higher than when they were at rest.

4,000 bird species regularly migrate, so they need to be well adapted for long flights



Soar like a bird

Many of the natural qualities of bird flight have inspired aircraft designers, meaning that some aspects of the planes we travel on are based on birds' features. Observing and transferring bird flight traits has led to the application of light frameworks and streamlined shapes.

One of the main qualities that enhanced aircraft was the curved surface of birds' wings to create uplift. The Wright brothers, who designed the first aircraft, studied these animals before twisting the shape of their aircraft's wings to match those of birds.

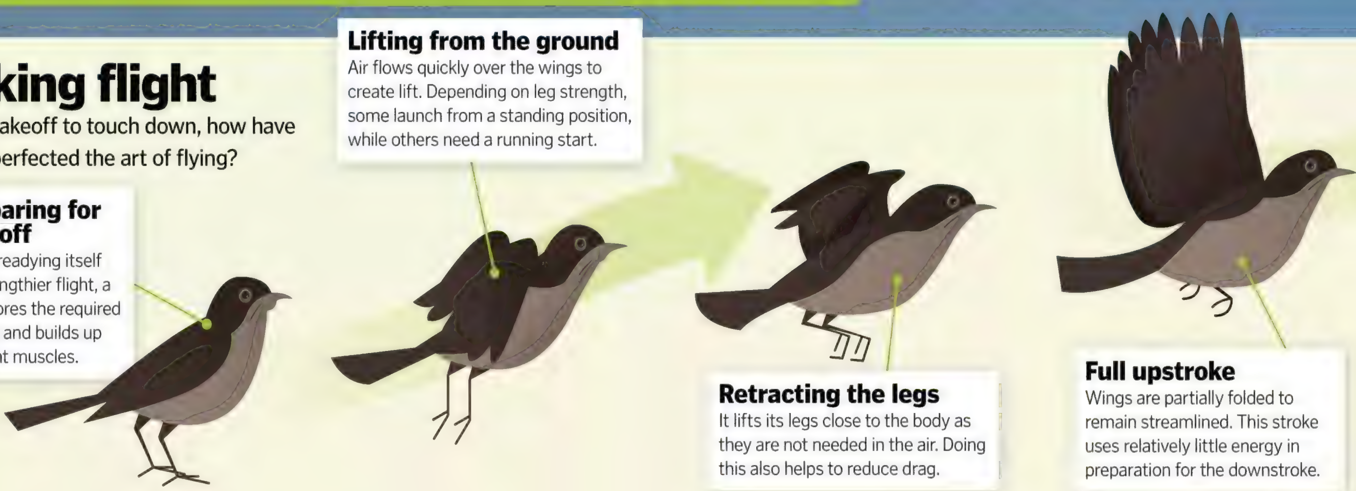
Hummingbirds can hover in the same spot for extended periods of time. Micro-helicopters aim to mimic this skill, but engineers are still working on how to improve the rotor power to achieve this.

Hummingbirds use over 20 per cent less power to hover than helicopters

"Aspects of the planes we travel on are based on birds' features"

Taking flight

From takeoff to touch down, how have birds perfected the art of flying?



Preparing for takeoff
When readying itself for a lengthier flight, a bird stores the required energy and builds up its flight muscles.

Lifting from the ground
Air flows quickly over the wings to create lift. Depending on leg strength, some launch from a standing position, while others need a running start.

Retracting the legs
It lifts its legs close to the body as they are not needed in the air. Doing this also helps to reduce drag.

Full upstroke
Wings are partially folded to remain streamlined. This stroke uses relatively little energy in preparation for the downstroke.

A bald eagle uses its large wingspan to glide through the air

5 FACTS ABOUT FLYING BIRDS

1 Weighty wings
Around a third of a bird's body weight is made up of the large wing muscles. These are the machines that power flight, keeping the bird airborne for large periods of time.

2 In a flap
Flapping is one of the most common flying methods, but it uses the most energy. Some birds alternate between flapping and gliding to conserve energy.

3 Hitching a ride
Taking advantage of the rising air thermals and updrafts, some birds soar in a circle around these areas to lift them higher, with minimal energy expended.

4 Mid-flight naps
Studies found that some birds can sleep while flying. Measuring electrical energy in the brains of great frigatebirds, results showed that they sleep in ten-second bursts during migration.

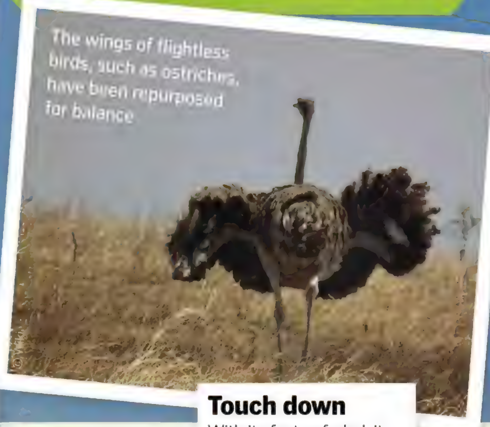
5 Furthest flyers
The Arctic tern has the longest migration of all the birds; over 80,000 kilometres a year. In their lifetime of around 30 years, their total flight distance is equal to three trips to the Moon and back.

The highest flyers

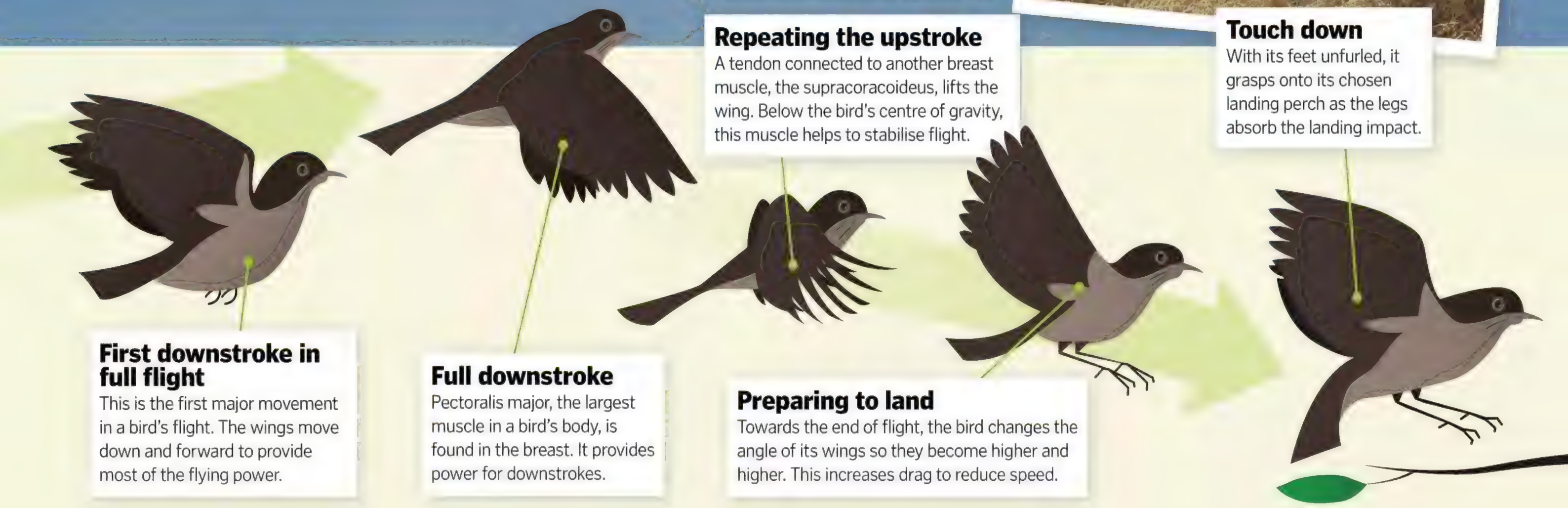
Rüppell's griffon vulture is the highest flying bird in the world, cruising at 11,000 metres in the air. Reaching the average flying height of a commercial aeroplane, these birds have evolved to carry a particular type of haemoglobin that absorbs oxygen more efficiently than in humans and other birds.

At great heights, these scavengers search for carcasses, their prime food source. These social birds can be found in their native home of Africa, nesting in colonies of around 200 birds, formed of pairs. They grow to have wingspans of 2.5 metres and can travel at speeds of over 35kph.

Flying near planes is dangerous. Griffon vultures have been known to be sucked into jet engines



The wings of flightless birds, such as ostriches, have been repurposed for balance



First downstroke in full flight
This is the first major movement in a bird's flight. The wings move down and forward to provide most of the flying power.

Full downstroke
Pectoralis major, the largest muscle in a bird's body, is found in the breast. It provides power for downstrokes.

Repeating the upstroke
A tendon connected to another breast muscle, the supracoracoideus, lifts the wing. Below the bird's centre of gravity, this muscle helps to stabilise flight.

Preparing to land
Towards the end of flight, the bird changes the angle of its wings so they become higher and higher. This increases drag to reduce speed.

Touch down
With its feet unfurled, it grasps onto its chosen landing perch as the legs absorb the landing impact.

Meet the LIVING FOSSILS

These creatures have survived asteroids, earthquakes and ice ages across millions of years to walk and swim the Earth today

Words by **Scott Dutfield**

The father of evolution, Charles Darwin, was the first to coin the term 'living fossil' in the pioneering book *On The Origin Of Species* in 1859. He used the term to describe living species bearing a physical resemblance to prehistoric species that once roamed Earth.

However, categorising animals as 'living fossils' has caused controversy in the scientific community because it implies that some of today's species have stopped evolving and remain unchanged from their ancient ancestors.

The truth about 'living fossil' species, such as crocodiles, is that they have very similar characteristics to a species that lived millions of years ago, rather than being unevolved for millions of years. To be classed as a living fossil a species must have had a significantly slower rate of physical evolution or show subtle morphological (physical) changes.

As evolutionary echoes, these modern-day doppelgängers give researchers a glimpse into their prehistoric timelines and offer suggestions as to why their morphology has gone almost unchanged for so long.

New additions to these evolutionary elites are still being discovered. In 2002, researchers unearthed the fossil remains of what was first believed to be a prehistoric chimpanzee in Barcelona. However, last year, after careful analysis, it was deduced that the fossils belonged to a giant flying squirrel (*Miopetaurista neogrivensis*), dating back 11.6 million years ago.

Nautilus

There aren't many species that can say they have lived to witness both the rise and fall of the dinosaurs, but nautiluses certainly can. Becoming giants of the sea around 500 million years ago, these ancient cephalopods owe their survival success to their natural armour. Nautiluses are the only cephalopods to have a fully enclosed shell, thanks to a fleshy trapdoor protecting the soft body that hides within.

At first glance, a nautilus may appear to be a floating snail, passively riding the underwater currents without any fins or limbs to guide its journey. However, it uses a water jet to propel itself through the sea. Through a siphuncle (a canal connecting living tissue to internal shell chambers), a nautilus can draw in and pump out surrounding water, allowing it to travel forwards and backwards. It uses the same method to ascend and descend: after expelling water from the shell, the nautilus becomes more buoyant and will rise; draw in more water and the cephalopod will sink.

Although this unique design has sustained these creatures for millions of years, they are now under threat of extinction from hunters fishing for their stunning shells.

© Getty

These living fossils use their 90 unsuckered tentacles to catch prey such as crabs and fish

Crocodiles have been around for 250 million years, but it was not until 65 million years ago that the species we recognise today first emerged

© Getty

Crocodile

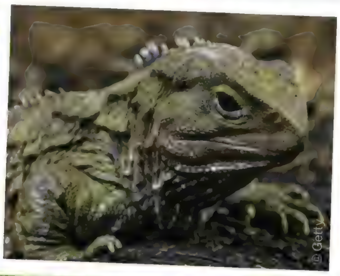
As the poster species for living fossils, crocodiles have long been an example of how "if it's not broken don't fix it" applies when it comes to evolution. At the start of the Mesozoic Era some 250 million years ago, the ancestors of modern-day crocodiles began to walk the Earth. By the late Cretaceous Period, around 65 million years ago, prehistoric swamps and riverbeds were home to amphibious predators not dissimilar to the crocodiles we see today.

Sporting long and muscular snouts, scaled armour and short legs, the physiology of crocodiles is believed to have evolved from the need to explore new hunting territories because dinosaurs had monopolised the land. Finding relief from this competition in the water, crocodiles evolved to suit their new habitat. Eyes, ears and nostrils lie on top of a crocodile's head to keep them above the water line while the rest of the body is submerged, and the muscular fin-like tail offers both power and manoeuvrability in the water.

Although we can see evidence that modern-day crocodiles have maintained their shape for millions of years, the lineage of the species has diverged. Over time crocodilians have taken many different forms, even vegetarian species – a far cry from today's carnivores.

The last lizard

Now only found in New Zealand, tuatara (*Sphenodon punctatus*) once roamed around the world. These lizard-like reptiles were previously thought to be a member of the lizard family, but after careful consideration and a fossil trail leading back more than 200 million years, it was concluded that these reptiles are members of an exclusive group known as Rhynchocephalia, of which tuatara is the only living member. There was 24 genera of Rhynchocephalia, but competition with other, more adapted reptiles, such as crocodiles, resulted in all but one becoming extinct around 100 million years ago.



© Getty

Tuatara is the last remaining member of the Rhynchocephalia reptiles

Prehistoric plants

Meet these thriving prehistoric plants

Cycad

Today cycads can be found on every continent except for Europe and Antarctica, and limited to tropical and subtropical areas. However, these plants once dominated the land as far back at 300 million years ago, with the earliest fossil records dating back to the Permian Period.

Monkey puzzle tree

Brushing shoulders with the dinosaurs during the Jurassic Period around 200 million years ago, monkey puzzle trees are among the oldest plant species to grow on Earth today. Living for 1,000 years or more, each tree and its limb-like branches are coated with tough spines for protection against hungry herbivores – both past and present.

Maidenhair tree

The fan-shaped leaves of the maidenhair tree have been waving in the breeze since around 350 million years ago. It's believed that this tree species, also known as ginkgo biloba, was saved from the brink of extinction by early humans. Grown as a source of food, decoration and medicine, maidenhair trees have flourished alongside our own evolution.

Liverwort

Soft organic matter such as leaves are tricky to find as fossils due to their high rate of decomposition. But every so often one makes an appearance. In the case of liverwort, a hardy, rock-clinging plant, fossil evidence suggests that it grew at least 350 million years ago.

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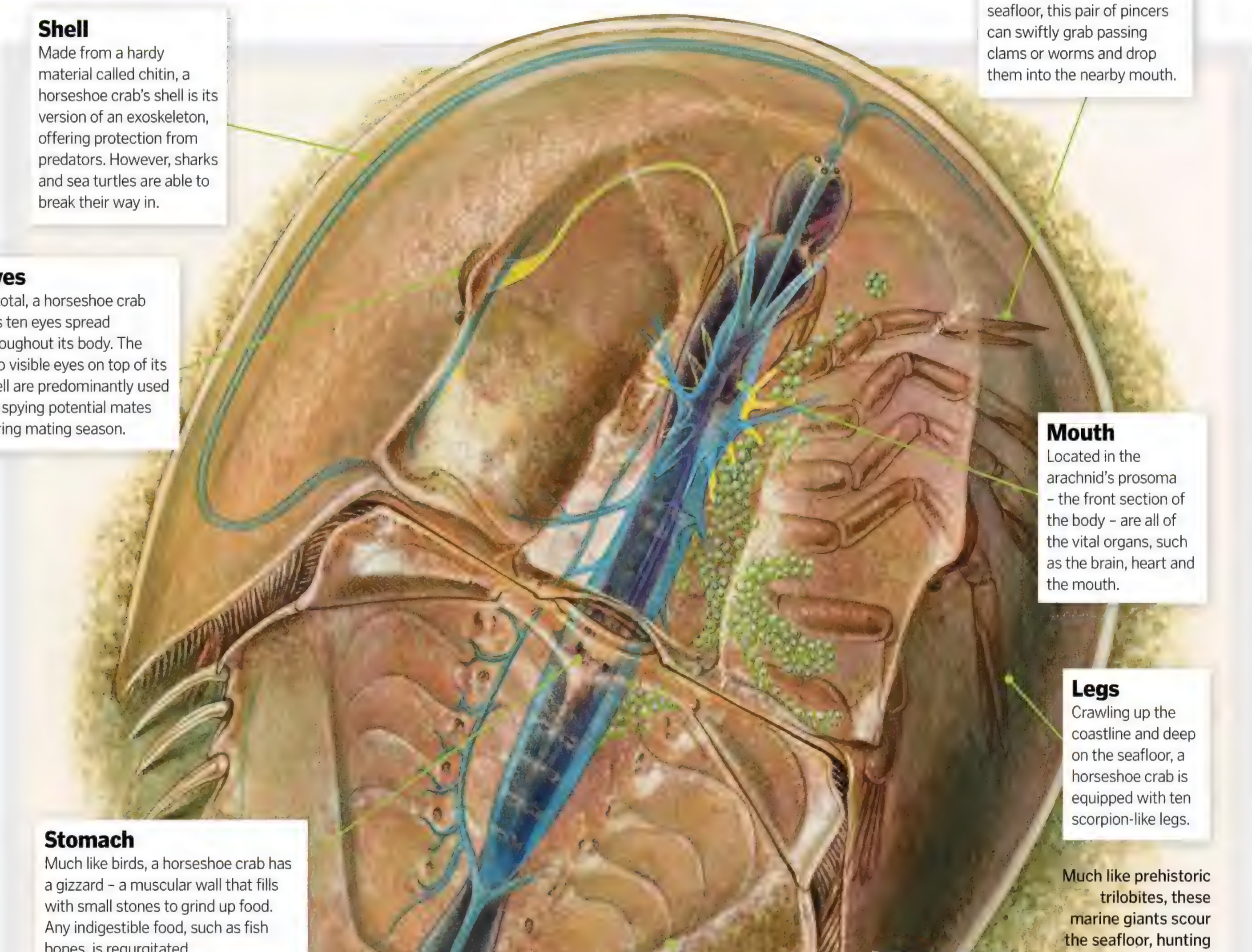
Beneath the armour

What lies beneath these benthic armoured giants of the sea?



Much like prehistoric trilobites, these marine giants scour the seafloor, hunting for food

Horseshoe crab

Despite their name, horseshoe crabs are not actually crabs, but instead belong to a group of invertebrates called arachnids, and are more closely related to spiders and scorpions. However, due to their crustacean-like shell, it's easy to confuse them.

First walking the seafloor over 300 million years ago, horseshoe crabs have kept up appearances ever since. Although not identical to their prehistoric ancestors, their evolution has been so gradual they have been labelled living fossils. Dressed in a robust horseshoe-shaped shell, these armoured arachnids make a tough meal for both prehistoric and present predators.

Although horseshoe crabs are not known for their swimming abilities and are more often seen scurrying from the water, they are still equipped with a long spine-like tail that acts as a rudder. In the event they find themselves on their back, this acts as a lever to flip them the right side up.

Each summer on shorelines around America, swarms of Atlantic horseshoe crabs head out of the waters and onto the beach to breed.


Coelacanths are elusive living fossils, swimming deep in Indonesian and African waters

© Alamy

Coelacanth

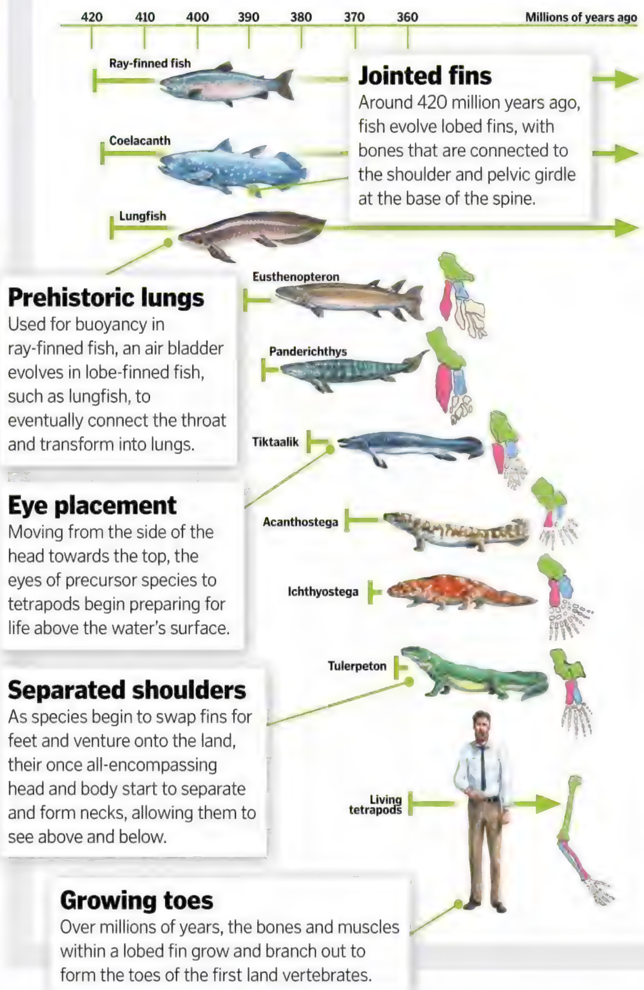
Taking a deep dive into the African waters surrounding the Comoros Islands, you might be lucky enough to spot a living fossil swimming near the seafloor. At up to two metres long, they're hard to miss. Once thought to be extinct, coelacanths have stood the test of time and remained relatively unchanged physically for over 360 million years.

There are currently two species of coelacanth – *Latimeria chalumnae* that dwell on the seafloor off the east coast of Africa, and *Latimeria menadoensis*, which swim deep in Indonesian waters. What makes these giant fish special is their fins. Typically, modern-day bony fish are ray-finned, meaning their flippers are made up of bony spines. Coelacanths are only one of two groups of fish to swim using lobed fins. Much in the same way our leg bones connect to our pelvis, lobe fins house an internal bone structure that has led scientists to believe their ancestry may be linked to the evolution of tetrapods (four-limbed vertebrates). However, having a lobed fin was as close as this fish got to sprouting legs.

To answer the question of which species started ditching fins for feet, the coelacanth's prehistoric cousin and fellow lobe-finned living fossil, the lungfish, may be responsible.

Ditching fins for feet

Although coelacanths still swim in the ocean, a group of their ancestors decided to escape the sea and walk on land. Here's how.



© Illustration by The Art Agency/Peter Scott

The original jellyfish

There's around 200 different species of comb jellyfish (Ctenophora) in the oceans, once thought to be the sister group to all other animals on Earth before sponges were proclaimed our evolutionary siblings. Comb jellyfish have been around for over 500 million years and were the first group of animals to swim using muscles. The name comes from the rows of structures called cilia, or combs. As cilia wave back and forth, a small current washes planktonic food into the jellyfish's mouths.


© Getty

Humans were once thought to be a long-distant relative of comb jellyfish

A case of misidentification

Although the term 'living fossil' has been awarded to species for more than 100 years, much like the principle of evolution, its accuracy has also changed over time. With the advancement in DNA analysis technology, scientists can determine how much change has occurred to a creature over time, or if it is what we think it is. Take the tadpole shrimp (*Triops cancriformis*), for example. Until 2013 these aquatic invertebrates were thought to be living fossils and had been linked to fossils dating back 250 million years. However, after researchers analysed the DNA of living tadpole shrimps, they discovered the species was not as old as they once believed and more likely evolved only 25 million years ago.

The uncertainty of this species' lineage stems from the similarity in appearance of different species of tadpole shrimp. Known as a cryptic species, one looks almost identical to the other, but they differ in their genetic makeup. In the 2013 study, 38 different species were identified based on genetics, with the majority yet to be taxonomically described.


Although it looks like a mini horseshoe crab, this tadpole shrimp doesn't share the same evolutionary lineage

SOLAR-POWERED ANIMALS

Most animals have to obtain carotenoids through their food, but pea aphids are able to make their own

© Alamy

Meet the creatures taking inspiration from plant photosynthesis and using sunlight to feed themselves

Words by **Scott Dutfield**

As Earth's natural solar panels, plants obtain energy from converting sunlight into food in a process called photosynthesis. It's an ability that has ensured the survival of autotrophs – an organism that produces its own food – for around 2 billion years. But it turns out plants don't hold the monopoly on photosynthesis, as a few animal species have also been found to dabble in the art of light conversion.

Take the pea aphid (*Acyrthosiphon pisum*), for example. Typically found feasting on the stems, leaves and flowers of alfalfa plants around the world, pea aphids have evolved to mimic their leafy lunch. Rather than producing chlorophyll pigment for photosynthesis, these tiny insects can produce another pigment called carotenoids, which can also absorb sunlight and provide an energy boost for the aphids. Although this isn't a complete replacement for the aphid's plant-based diet, studies have shown green aphids produce significantly higher levels of adenosine triphosphate (ATP) – the body's energy currency – than their white counterparts, who lack the carotenoid pigments. Pea aphids are a great example of how one species can mimic another to reap the same benefits through evolution.

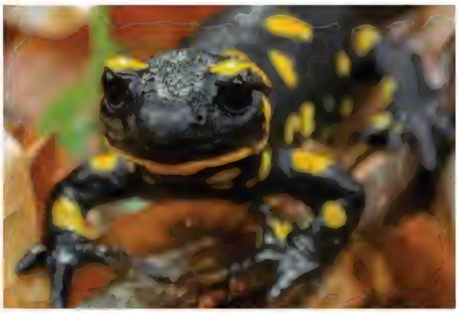
Just below the watery surface of salt marshes around the North American coastline, there is also a group of sun-worshipping slugs with a tendency to steal the ability to photosynthesise from their algae neighbours. Looking more like the leaf of a sycamore than a sea slug, sacoglossans are a group of marine invertebrates that feed on algae and in the process absorb their photosynthesis factories, chloroplasts. Known as kleptoplasty, sacoglossans can strip chloroplasts from their algal prey and relocate them into their own cells, where they continue to produce energy and sugars from sunlight. These sea slugs only need to feast on marine algae for the first two weeks of their life, which can sustain them for around 12 months.

One slug has taken this chloroplast kleptomania to the next level by stealing the algae's genetic information to produce its own chloroplasts. Although sacoglossan

© Alamy

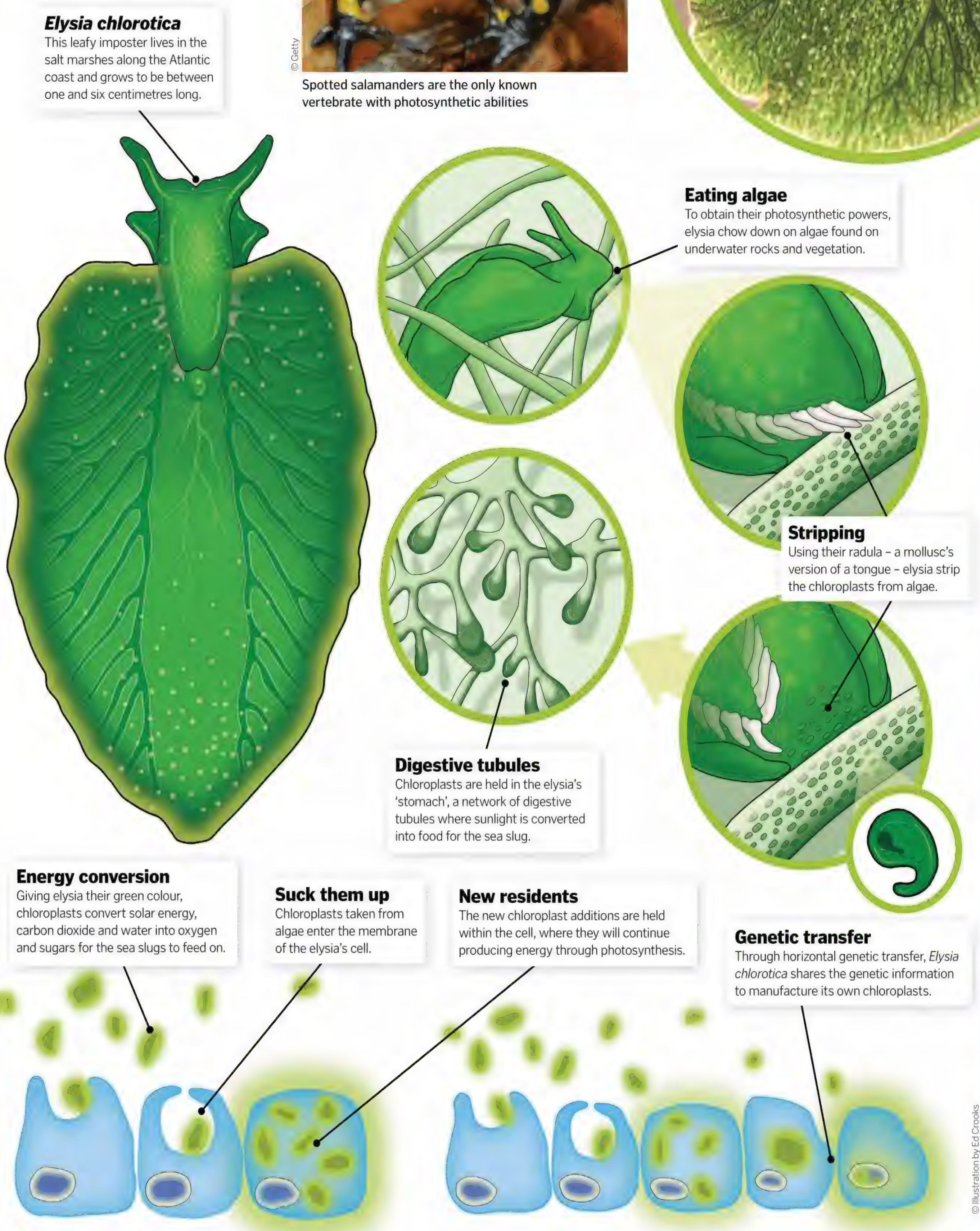
STEALING ENERGY FACTORIES

How the emerald elysia strips algae of their photosynthesis powerhouses


© Getty

Spotted salamanders are the only known vertebrate with photosynthetic abilities

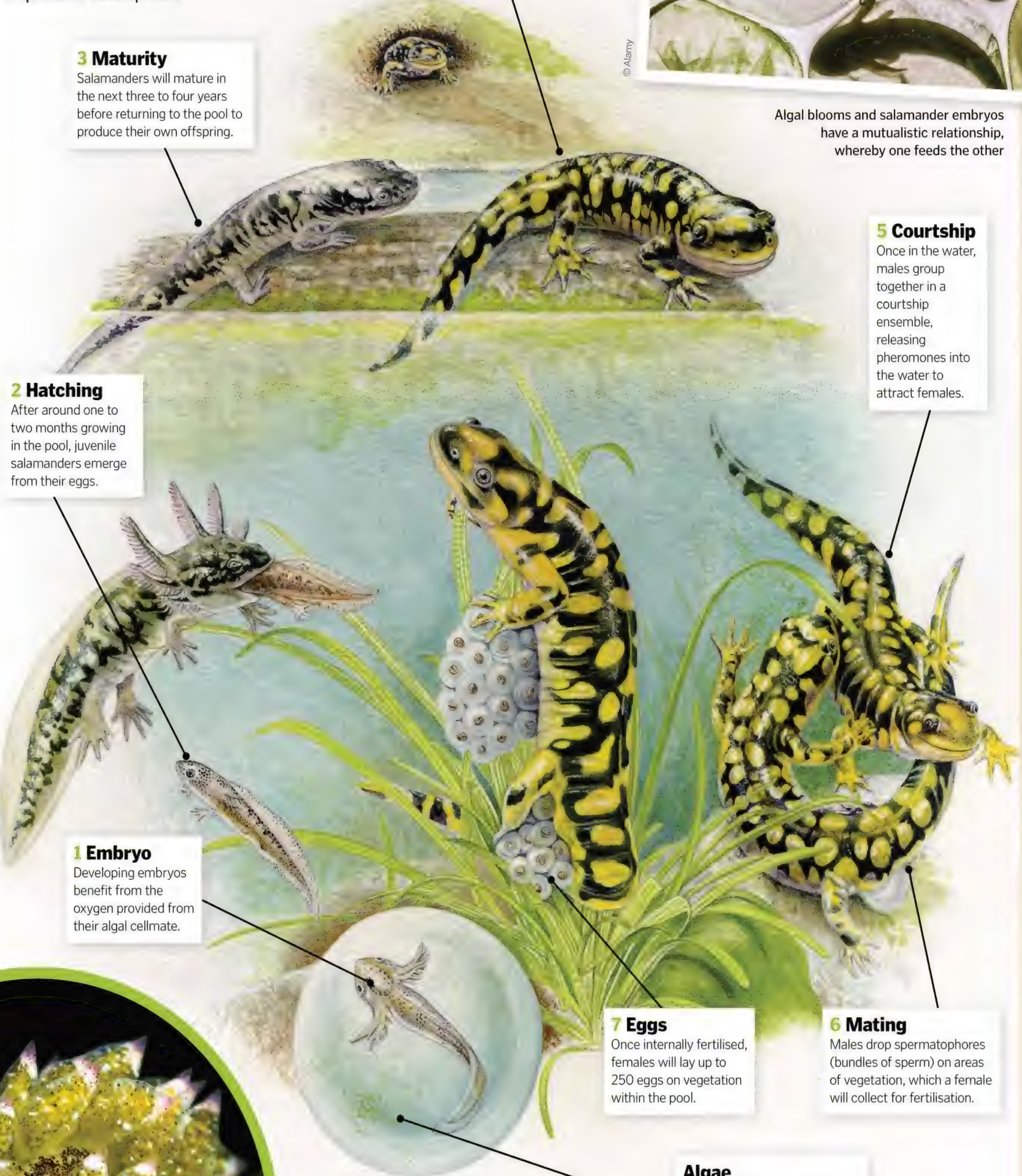
Elysia chlorotica is a member of a genus capable of stealing algaes' method of energy production



Algal blooms and salamander embryos have a mutualistic relationship, whereby one feeds the other

SPOTTED SALAMANDER LIFE CYCLE

How algae has shaped this amphibian's development



4 Homeward bound
Adult spotted salamanders journey from their forest homes to the seasonal pools they originally hatched from.

3 Maturity
Salamanders will mature in the next three to four years before returning to the pool to produce their own offspring.

5 Courtship
Once in the water, males group together in a courtship ensemble, releasing pheromones into the water to attract females.

2 Hatching
After around one to two months growing in the pool, juvenile salamanders emerge from their eggs.

1 Embryo
Developing embryos benefit from the oxygen provided from their algal cellmate.

7 Eggs
Once internally fertilised, females will lay up to 250 eggs on vegetation within the pool.

6 Mating
Males drop spermatophores (bundles of sperm) on areas of vegetation, which a female will collect for fertilisation.

Algae
Algal blooms form within the egg of a developing salamander, where they feed on excess carbon dioxide and nitrogen created by the embryo.

Japan's leaf sheep (*Costasiella kuroshimae*) is another sea slug capable of stealing algae's ability to photosynthesise

slugs can survive for a whole year without eating before they run out of photosynthesis power, the emerald elysia (*Elysia chlorotica*) has evolved a way to make sure it never runs out of reserves. Initially grazing on algae and obtaining chloroplasts through kleptoplasty, the emerald elysia breaks into the nucleus of the algae and steals genetic information which codes for the production of chloroplasts in what's known as a horizontal genetic transfer. This sea slug is then able to sustain itself on the energy produced through photosynthesis, even though they still chow down on an algal lunch from time to time.

> "Algae become incorporated into the salamander cells"

With only a few examples of animals capable of exploiting photosynthesis, especially in vertebrate species, you're not going to see green bears in the woods anytime soon. However, one vertebrate species has been discovered to harbour an algal hostage within its cells. It was previously believed that during the life cycle of the spotted salamander (*Ambystoma maculatum*), algae and a salamander embryo have a symbiotic relationship whereby both benefit from the other in the exchange of nutrients for oxygen. However, studies have shown that during development algae become incorporated into the salamander cells, where they live and provide energy to adult salamanders. It's still relatively unclear as to how exactly the algae enter the salamander's cells and why its immune system doesn't deem the algae as a threat. But what is clear is that once inside, this microscopic mutualism is no longer beneficial to both sides. Trapped in the confines of an amphibian's dark-pigmented body, access to a source of light is in short supply. Instead, these once-photosynthetic algae turn their hand to fermentation to produce food in the gut of the salamander.

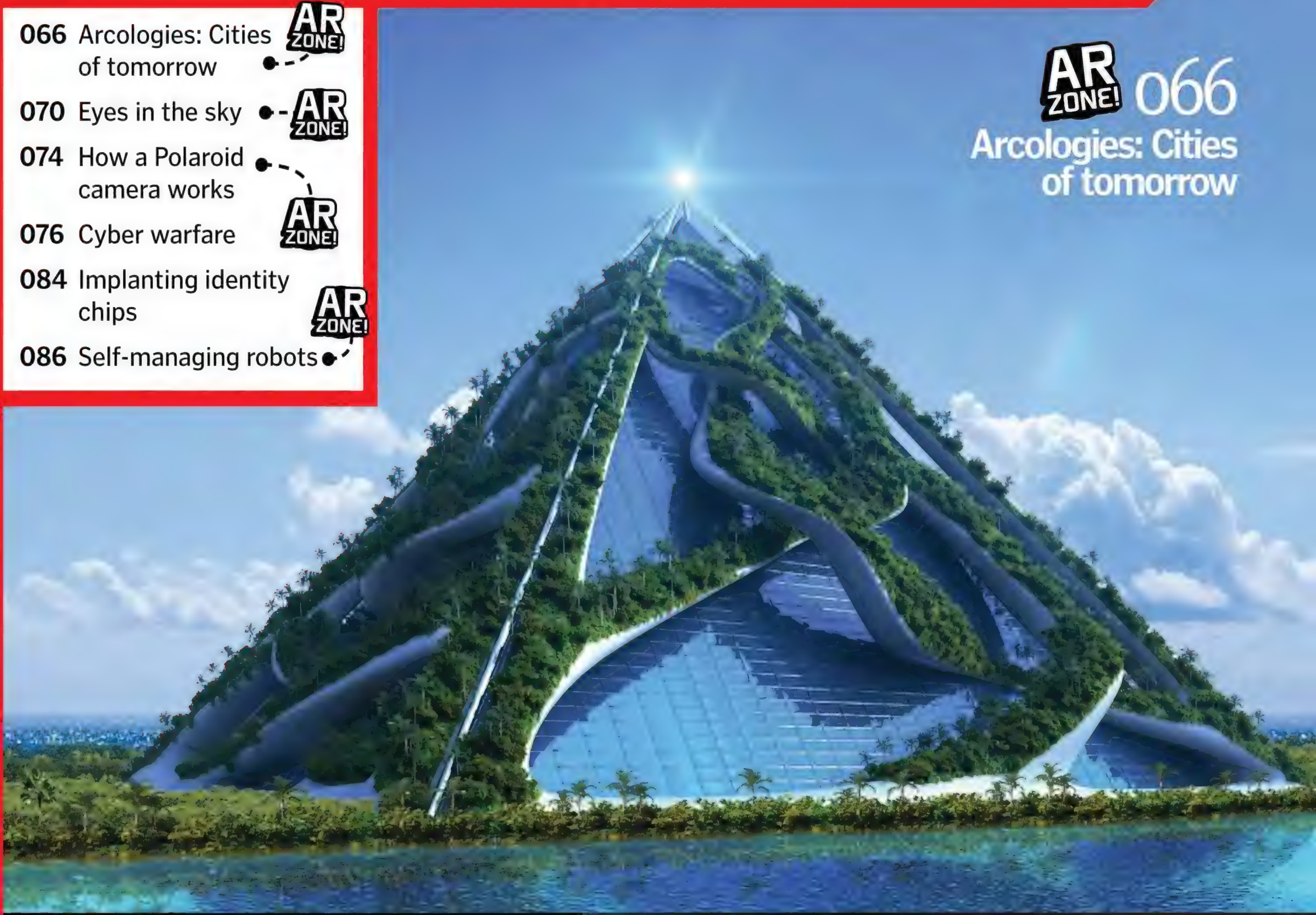
Indian pipe (*Monotropa uniflora*), is one of the many non-photosynthetic plants that sucks the life out of other organisms

© Alamy

It's not easy being green

Plants aren't always the leafy green photosynthetic organisms we think they are. Around 3,000 plant species around the world are non-photosynthetic, seeking food in other ways. One such plant is the Indian pipe (*Monotropa uniflora*). Looking more like the ghost of plants past, this colour-lacking sprout is missing any chlorophyll to convert light into energy. Instead, these North American plants obtain sugars from surrounding fungi. Known as a myco-heterotroph, Indian pipe take advantage of a group of fungi called mycorrhizae, which typically have a symbiotic relationship with other plants, trading sugars for other plant-produced nutrients. However, this ghostly species only offers a one-sided deal, stripping the fungi for its own gain.

TECHNOLOGY



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Arcologies: Cities of tomorrow

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Self-managing robots

AR ZONE!
084
Implanting identity chips


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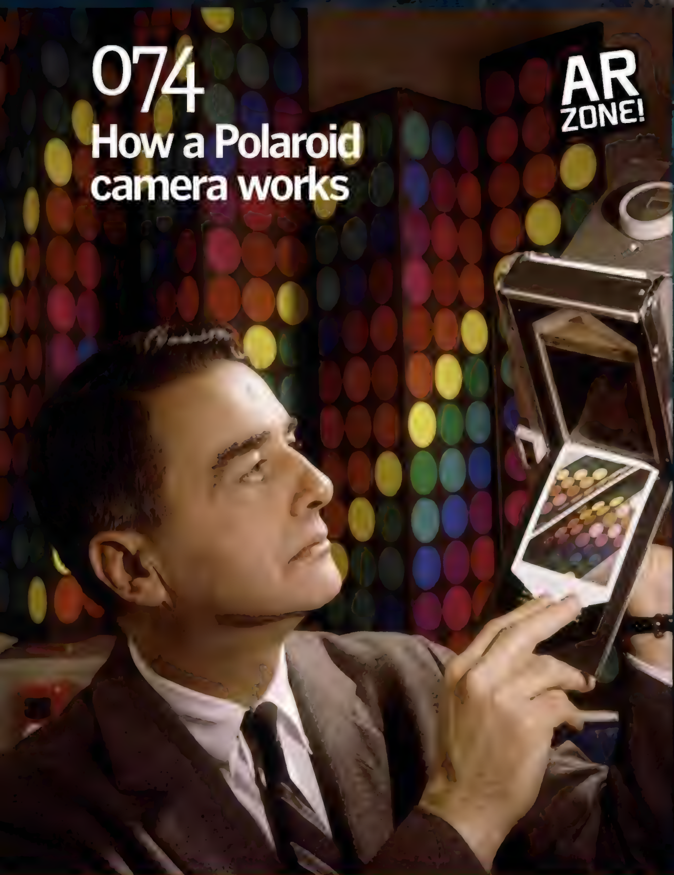
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ARCOLOGIES CITIES OF TOMORROW

Could these self-sustaining metropolises revive our planet?

Words by Ailsa Harvey

© Getty

As a species, we sometimes live in our own little bubble. Using the resources available to us for a variety of needs, we have caused a significant impact on the planet. Now plans are in place to use our own bubble for the better: to literally live in one.

To sustain our population while helping to prevent damage to the world, we could soon settle into newly designed cities called arcologies. Many different habitat variations are being worked on, with most of them including natural, alternative ways to sustainably source enough energy for those who live there.

Arcology is a futuristic initiative that aims to condense settlements into self-sustained cities that limit human impact on the environment. The name and idea came from Paolo Soleri in 1969, who decided to merge concepts of architecture with ecology. His proposal focused on providing for the essential needs of our population in an environmentally friendly design. Current architecture means today's cities and towns are dominated by low-rise buildings and car-dependant travel. In Soleri's alternative, giant structures would be built for the most efficient use of space. The majority of arcology designs showcase high-rise constructs that accommodate thousands of people.

But how will these gigantic habitats reduce our impact on the planet? Being densely populated, large amounts of energy would need to be cultivated within a relatively small area. Soleri's first design included concrete domes, placed to maximise their ability to capture the heat and light energy from the Sun at all times, even when the Sun's at its lowest in the sky and during the winter. This had the added benefit of creating shade during summer.

One of the drawbacks of having a number of different arcologies is the issue of separation. Before the world commits to these living arrangements, all our basic human needs have to be catered for within these settlements, including the requirement that we can remain connected to the outside world in some way.

Feeding the thousands

Where are all these arcology residents going to source their food from? One proposed design is a vertical farm. Farmland currently takes up around 11 per cent of the Earth's land, but if we stacked these fields, we could use the same area but on multiple levels, so more space can be left for nature.

This design displays an impressive 15-storey farm with a total area of 5,200 square metres of space in which to grow crops. The building is separated into wings to maximise sunlight. This could provide 1,000 people with their basic calorific needs, and in embracing a plant-based diet, production of harmful emissions would be reduced.

As part of the process, the arcology inhabitants would assist production. During waste treatment, methane would be extracted and used to run generators. The system has other solutions that ensure no material is wasted. Any water not used in farming would be collected at the bottom, condensed by dehumidifiers and returned to living blocks to be used in other ways.

Most water consumed by plants is returned as water vapour, and dehumidifiers can collect water for residents

Nobody wants to feel like they are in a cage, so to tackle this issue, shuttle designs are being explored for travel between settlements, and some of the planet's natural environment could be incorporated within the structures.

Though the positive impact of arcologies can be predicted, any detrimental effects on the environment that isolating us from the rest of the planet might have is less clear. Where a physical barrier will seclude our species, there is no way of knowing how this will influence ecological relationships with outside organisms. Arcologies, therefore, are certainly much more than just an architectural challenge, but represent a significant change for the whole planet.

Today's arcology designs

Self-sustaining settlements are already being planned across the world

Over 40,000 people visit Arcosanti every year

© Carwil

Arcosanti

Location: Arizona, USA

Designed by Paolo Soleri himself, this arcology for 5,000 inhabitants has been a work in progress since 1970. Situated at an altitude of over 1,000 metres in an isolated desert, the site is currently used as a prototype to demonstrate the possibilities of arcologies to thousands of visitors each year.

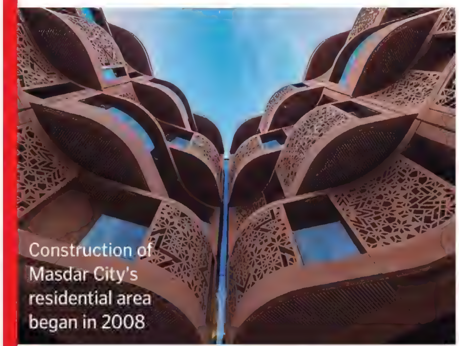
Crystal Island will contain a school for 500 pupils

© Foster & Partners

Crystal Island

Location: Moscow, Russia

Currently postponed, this arcology was to have the largest floor space on the planet (2.5 million square metres). Its buildings will be encased in one huge breathable tent. Being sealed in winter will help to conserve heat, while being open in the summer months will help to naturally cool the interior.



Construction of Masdar City's residential area began in 2008

Source: Wikimedia Commons/Sa7er90

Masdar City

Location: Abu Dhabi, UAE

This settlement's primary aim is to reduce fuel consumption and pollution. Powered entirely by renewable sources such as solar panels, wind farms and geothermal energy, it will also have a solar-powered desalination plant, which will provide clean, fresh water, and most of the water will be recycled and reused.

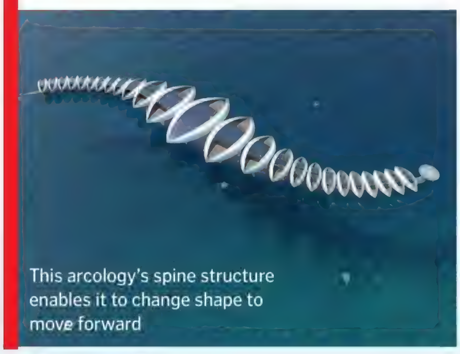
The building's eight modules can extend their hydraulic legs to overcome snow accumulation

© Hugh Broughton Architects

Halley VI Research Station

Location: Antarctica

In remote areas of climate-sensitive Antarctica, research teams are already utilising self-sustaining habitats in the challenging environment. Operated by the British Antarctic Survey, this research station is used for Earth, atmospheric and space weather observation.



This arcology's spine structure enables it to change shape to move forward

© Gianluca Santosuosso

HYPERcay

Location: The oceans

This building concept was inspired by cruise ships, but there's more to it than leisure. Self-contained, with solar panels, vegetable gardens and rainwater-collection facilities, this arcology floats on water, enabling mankind to adapt to Earth's rising sea levels. It will use its unique shape to generate propulsion.

LEAN LINEAR CITY

Combining city life with nature, this proposed arcology is an eco-friendly living arrangement that doesn't isolate its communities from other settlements

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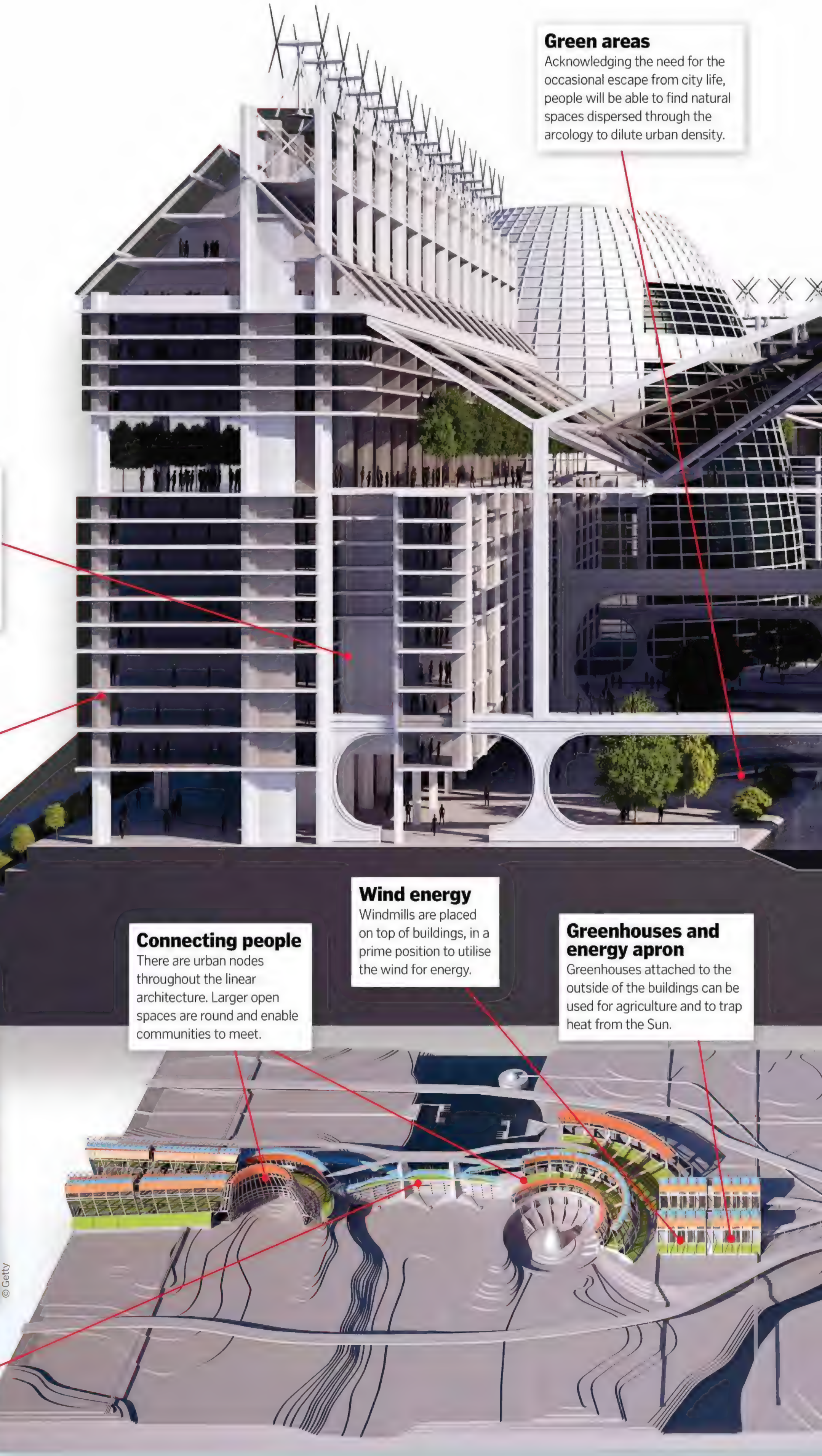


Light well
Making the most of an area as living space means that some residents stay in rooms deep in the centre. Light wells allow daylight to enter, brightening up areas that would otherwise have no natural light.

Main structure
At over 20 storeys high and stretching for many kilometres, two main structures will be built in modules. These modules could accommodate 3,000 residents each.

Green areas
Acknowledging the need for the occasional escape from city life, people will be able to find natural spaces dispersed through the arcology to dilute urban density.

Wind energy
Windmills are placed on top of buildings, in a prime position to utilise the wind for energy.

Connecting people
There are urban nodes throughout the linear architecture. Larger open spaces are round and enable communities to meet.

Greenhouses and energy apron
Greenhouses attached to the outside of the buildings can be used for agriculture and to trap heat from the Sun.

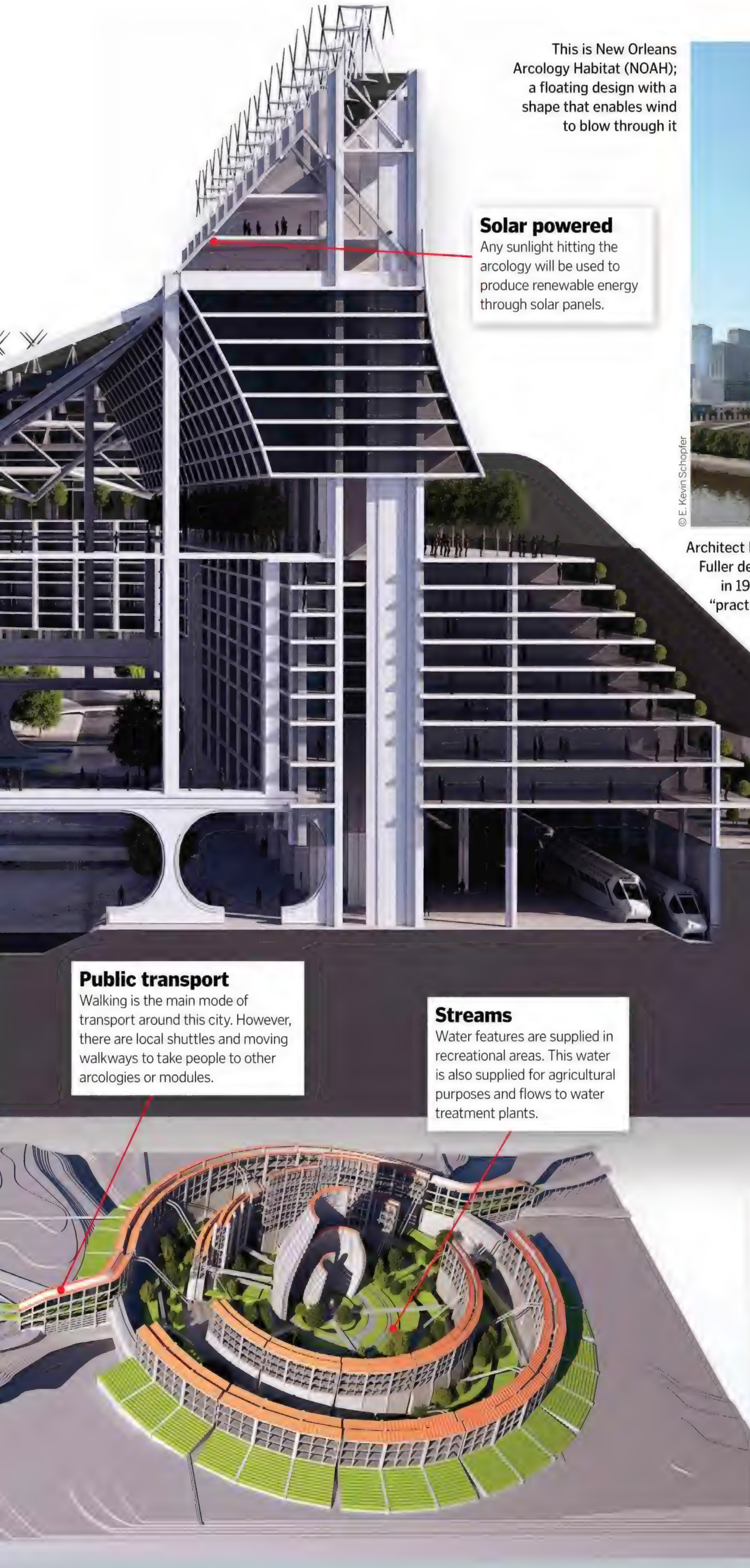
Arcology founder Paolo Soleri, pictured standing outside Arcosanti in 1976

© Getty

Multifunctional bridge
While bridges add to the sense of connection, they can also act as a dam for the arcology's water supply.

This is New Orleans Arcology Habitat (NOAH); a floating design with a shape that enables wind to blow through it

© E. Kevin Schopfer

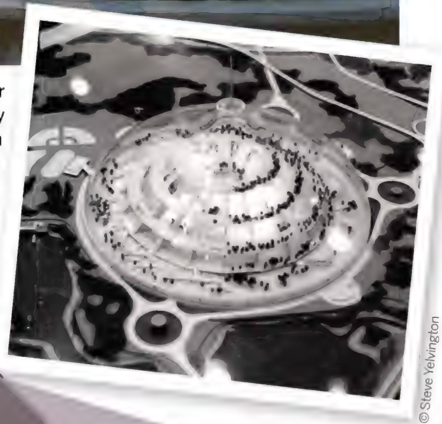


Solar powered
Any sunlight hitting the arcology will be used to produce renewable energy through solar panels.

Public transport
Walking is the main mode of transport around this city. However, there are local shuttles and moving walkways to take people to other arcologies or modules.

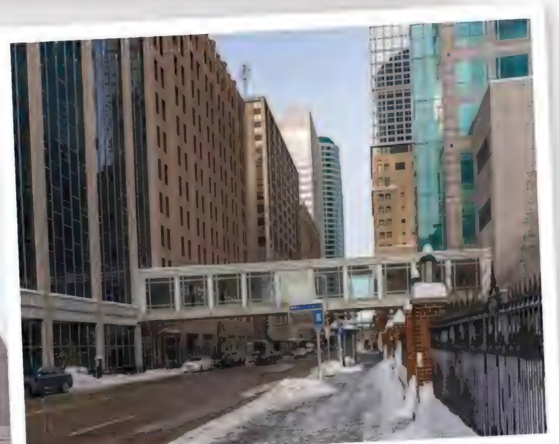
Streams
Water features are supplied in recreational areas. This water is also supplied for agricultural purposes and flows to water treatment plants.

© Illustration by Nicholas Forder



Architect Richard Buckminster Fuller designed this arcology in 1971, describing it as a "practical way for humans to live together economically"

© Steve Yelvington



© Tony Webster

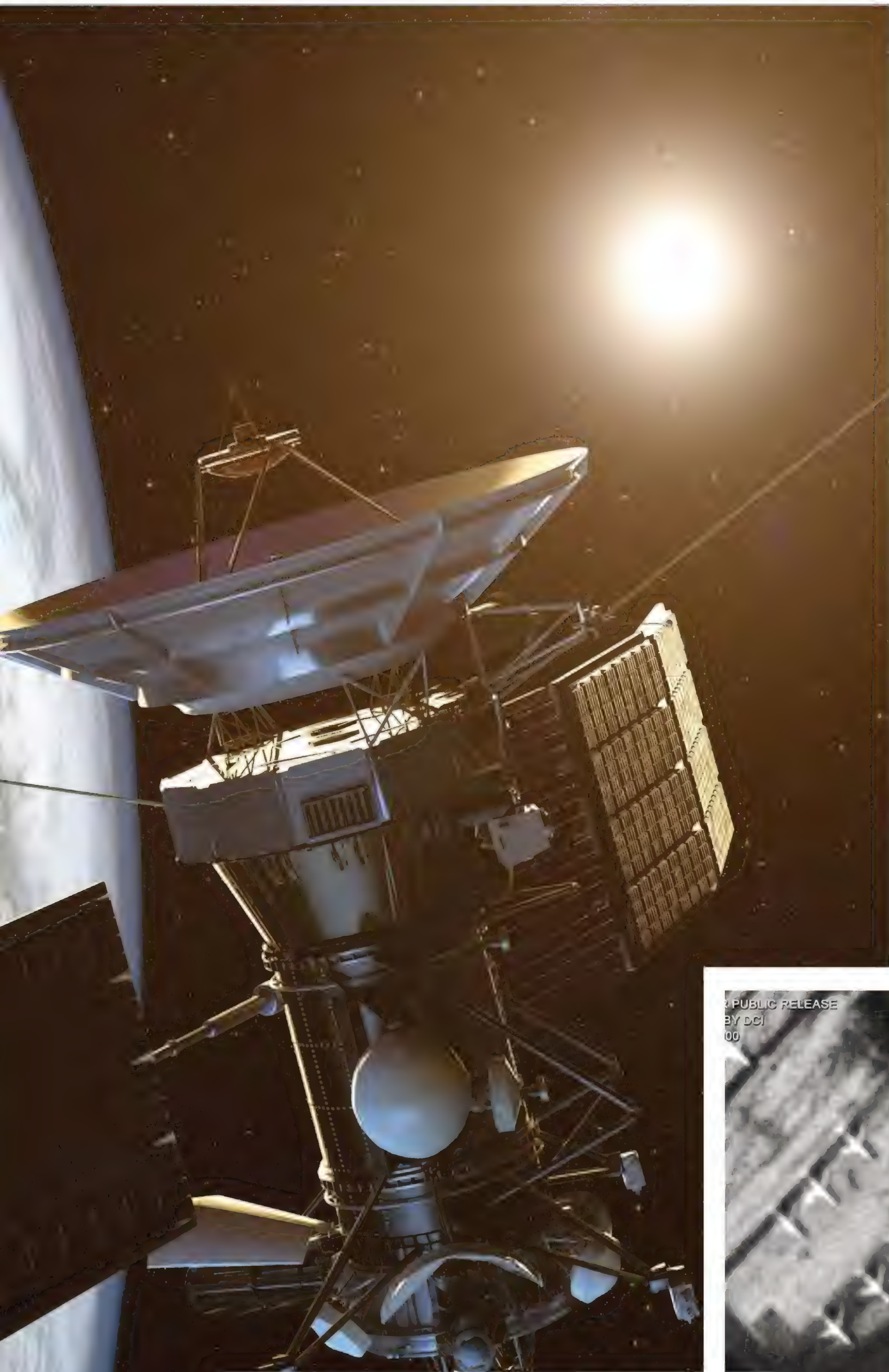
Minneapolis skyways show how some cities already use connected architecture

EYES IN THE SKY

How all-seeing satellites watch the world from the safety of space

Words by **Baljeet Panesar**

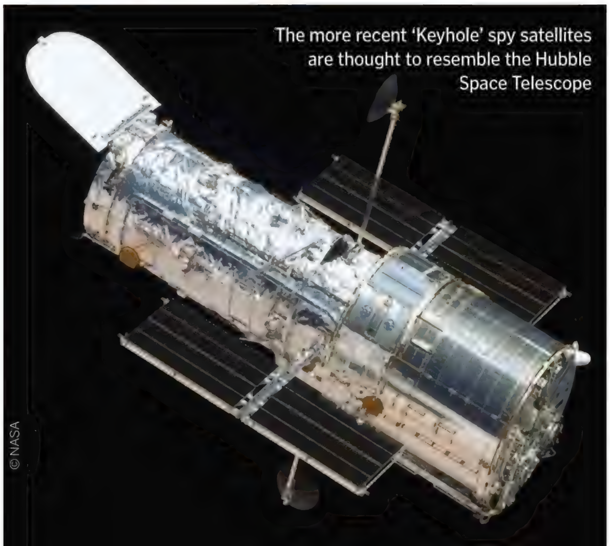
© Getty



Ever since the launch of the first satellite, Sputnik, by the USSR in October 1957, thousands more have orbited – and remain orbiting – the Earth. We don't tend to hear about reconnaissance, or spy satellites though, and as their missions are classified, their equipment and capabilities are often not disclosed. Hundreds of these secretive spies in the sky have been launched since the 1960s.

Spy satellites are used for both military and intelligence purposes, including detecting troop movements, monitoring the dismantling of nuclear weapons and radio signals, spotting missile launches and providing precise positional information. Flying high above the surface of Earth, these eyes are free to scan the ground below with their most important asset – their onboard camera. It's estimated that these satellites can see objects on the ground that are just ten centimetres across – enough to see an individual person in a crowd. These use the same technology that's in your smartphone – a charge-coupled device (CCD) – a sensor that converts light into electrical signals. These are stored on the satellite's onboard computer until it can send the encrypted information back to the ground. Satellites must also have a source of power, in many cases either solar or nuclear, and a means of controlling their altitude, such as via thrusters. There are also radio-listening spy satellites that can listen to radio signals that are being transmitted by another satellite.

A KH-9 satellite image of an airfield near Moscow, taken in 1979



The more recent 'Keyhole' spy satellites are thought to resemble the Hubble Space Telescope

Anatomy of a spy satellite

Discover what lies within these top-secret electronic spies

Relay antenna
Satellites use radio waves to downlink imagery back to ground stations on Earth from an altitude of about 320 kilometres.

Thrusters
From manoeuvring itself into the correct orbit to maintaining its position on a target, all satellites need a way of moving through space.

High-resolution camera
CCDs gather images to form a digital photograph that's transmitted back to Earth.

Primary mirror
Reportedly some spy satellites have a primary mirror that's 2.4-metres wide – the same diameter as that of the Hubble Space Telescope.

Avionics
The satellite's electrical systems and software act as its brain, telling it what to do and where it needs to be.

Solar panels
Large, fold-out panels harness the Sun's energy into electricity to power the satellite.

Secondary mirror
A steerable secondary mirror helps to enhance the sharpness of the images taken by the satellite.

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5 FACTS ABOUT MILITARY AND INTELLIGENCE SATELLITES

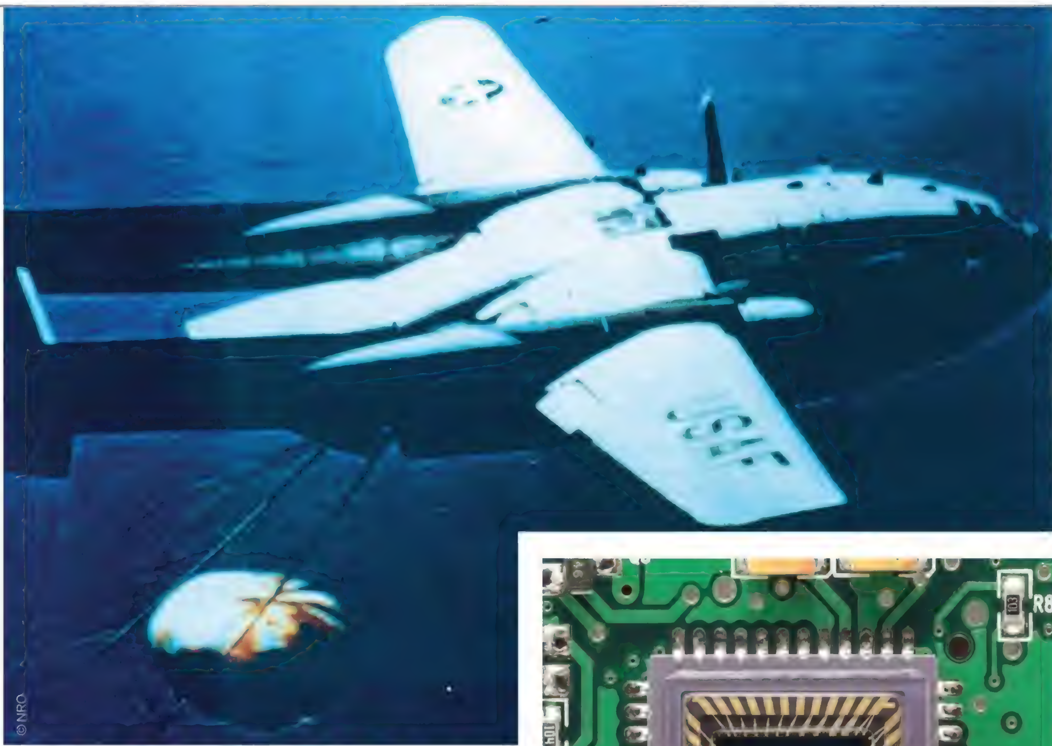
1 Zenit
The USSR's Zenit satellites were launched between 1961 and 1994, disguised as scientific exploration missions using the name Kosmos. Over 500 satellites were launched between 1981 and 1994.

2 SAR-Lupe
Germany's first reconnaissance mission is used by the military, and it's made up of five satellites that were launched over a period of two years.

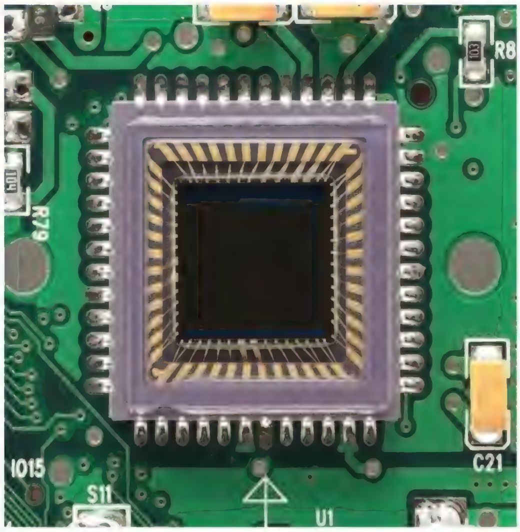
3 Information Gathering Satellite (IGS)
After a North Korean missile test over Japan in 1998, Japan's first spy satellite was launched in March 2003. The country's most recent intelligence-gathering satellite was launched in February 2020.

4 Zircon
This was supposed to be Britain's first spy satellite, but the project was cancelled in 1987 because it was too expensive.

5 KH-11 Kennen
The first US spy satellite that used digital imaging was launched in 1976, and over its lifetime there have been five different generations.


© NRO

A C-119 aircraft catches a recovery capsule that contained the first reconnaissance images from space in mid-air


© Alamy

Silicon is used to make CCDs because of its semiconductor properties

During the height of the Cold War, the US felt threatened by a nuclear attack from the Soviet Union. The US used aircraft and balloons to spy on the Soviets, but after one of the US' U-2 spy planes was shot down, the country needed other ways to gather intelligence, so space-based photo reconnaissance satellites were developed. The programme was called Corona and was approved months after the Soviets launched Sputnik.

These early spy satellites, however, were nothing like modern-day reconnaissance satellites; they used photographic film to store photos that were then returned to Earth in a 'film bucket' that was caught by an aeroplane in mid-air at about 4,572 metres. Modern-day satellites can stay in orbit for years, while the Corona satellites were limited by the amount of photographic film they had on board – at most they could only stay in orbit for a few weeks. Over its 12-year lifetime the Corona programme collected more than 800,000 images, each of which had to be carefully scrutinised by humans working on the project.

Recently the National Reconnaissance Office (NRO) has been working on an elusive project named Sentient, an AI spy system that's like an all-knowing, all-seeing brain in the sky. The programme can process vast amounts of information and combines this with satellite data to learn about the world below and respond in real time. Given its classified nature, however, its true capabilities will never be known, and it could be used without us ever knowing.

Satellite-on-satellite spying?

On 20 January 2020, something highly concerning happened hundreds of miles above the Earth's surface. A Russian inspector satellite, called Kosmos 2542, manoeuvred itself behind USA-245, an imaging spy satellite. Instead of passing each other every 11 to 12 days, however, there's now less than 300 kilometres between them. Experts believe that the Russian satellite is trying to gather information about the US mission; its radio-frequency probe could tell the Russians what pictures it's taking and how it processes the data. What's even more suspicious is that they're closest to each other when in sunlight – the perfect conditions for surveillance.

Although the evidence is coincidental, Russia's not breaking any rules, so there isn't much that the US can do about it. There are, however, growing concerns about the increasing militarisation of space.


A Delta IV Heavy rocket was used to launch USA-245 on 28 August 2013

© U.S. Air Force/Joe Davila

How a Polaroid camera works

Take a look inside the instant camera that inspired generations of photographers

The invention of Polaroid cameras marked the beginning of a new era for photography. Today, we may take for granted the ability to instantly analyse our photos – zooming in on details on a digital screen before declaring the result unsuitable and taking another.

But prior to the 1950s, photographers had to wait between 30 minutes and two hours for their photos to be developed. If an image turned out badly, your subject could be gone, along with your opportunity for the perfect shot. This was until one man sought to change all that.

Instant photography was brought about by Edwin Land, although his three-year-old daughter also gets some of the credit. When spending a day at the beach, she didn't understand why she couldn't see the picture her father had taken of her. This made Land ask himself the same question, sparking the ideas that circulated in his mind. The outcome meant his daughter would grow up never needing to wait for a photograph again.

"Polaroid's Land Camera gained instant popularity, selling out in a day"

The first instant camera appeared in 1947. Named after its inventor, it was called the Land Camera. Consisting of a roll of positive paper and developing chemicals, the camera worked by bringing the exposed negative and the positive paper together through rollers.

In the click of a button, the camera's shutter opened, allowing light to enter. This hit the extremely photosensitive film, and the light recreated the scene before the camera.

Light energy ionised the film's silver halide coatings, converting them to metallic silver atoms. The number of silver atoms on each part of the film was proportional to the light exposed on the image. After around 60 seconds, the negative paper was peeled from the positive image to reveal the finished photograph.

Polaroid's Land Camera gained instant popularity, selling out on the first day. The product made $5 million in its first year, and at Polaroid's peak 1 billion shots were being snapped a year.

The camera's mechanics

The Polaroid Land SX-70 instantly produced clean photographs automatically

Instant colourisation

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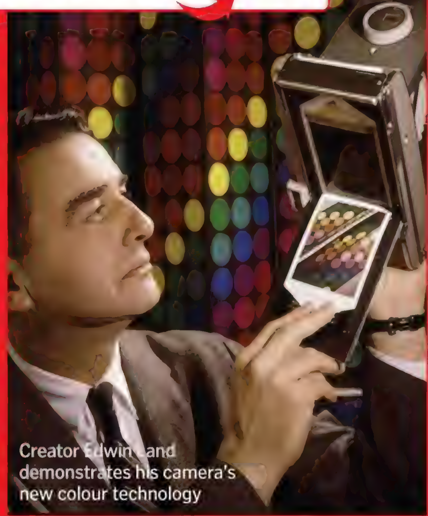
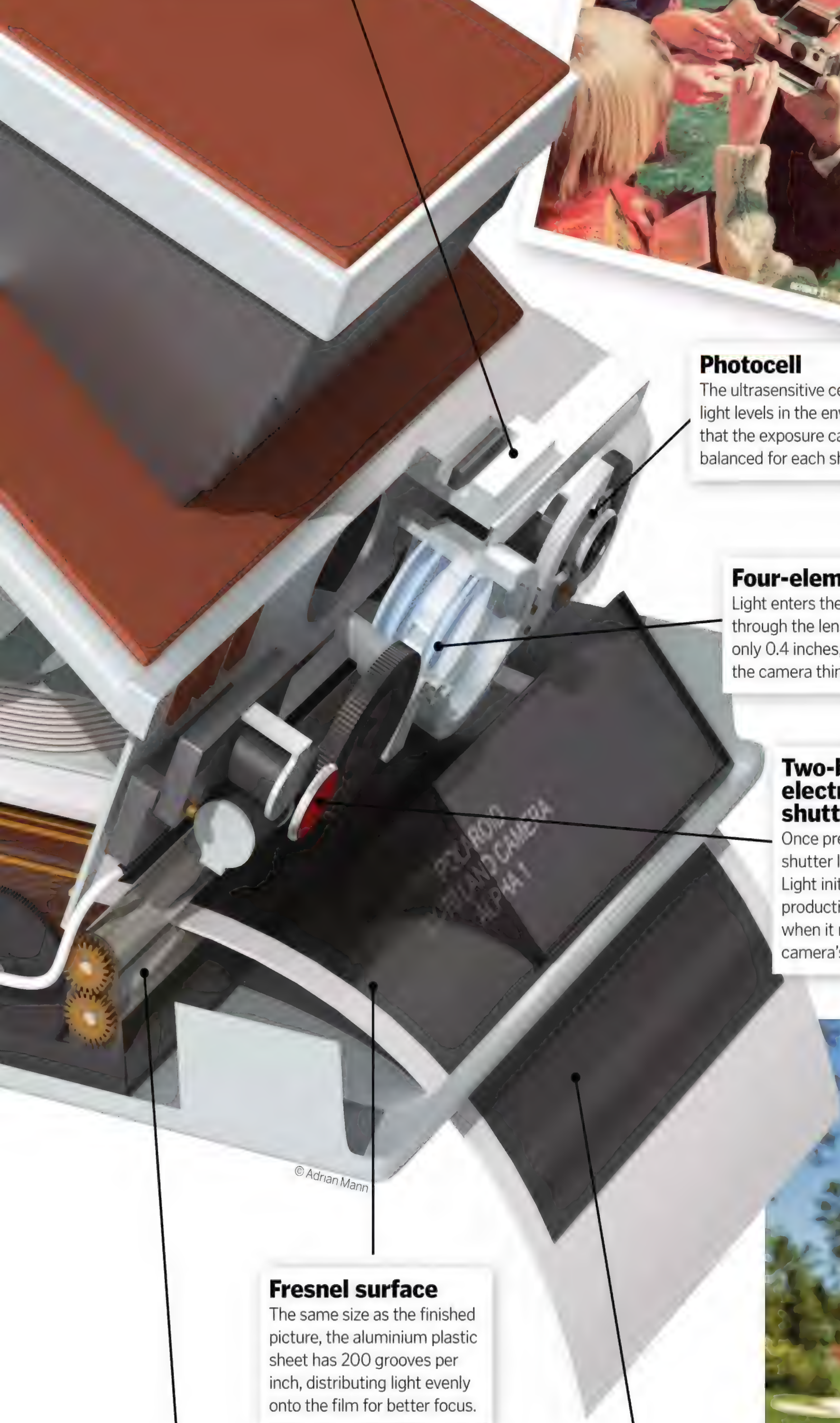
In 1963 Polaroid launched its instant colour film after the invention of dye-developer molecules. Whereas black and white instant cameras use one film covered in silver halides, coloured Polaroids have three, with each coating representing a different part of the light spectrum: blue, green and red.

Colour photography wasn't new, but there was something striking about holding a picture identical to what stood before you just seconds before. As well as amateurs using it to create lasting memories, renowned photographers also praised this new addition. Andy Warhol used these cameras to create early selfies, and his photographs of himself and others acted as a sketchbook, inspiring his colourful work.

Warhol took his Polaroid camera everywhere with him, continuously shooting and documenting his surroundings. When he died he left over 60,000 Polaroids and snapshots behind.


Creator Edwin Land demonstrates his camera's new colour technology



Lighten/darken control
Using data from the photocell, this control signals the shutter to open to the correct aperture. Widening the shutter increases exposure.

Photocell
The ultrasensitive cell detects the light levels in the environment so that the exposure can be balanced for each shot.

Four-element lens
Light enters the camera through the lens. Measuring only 0.4 inches, its size keeps the camera thin when folded.

Two-bladed electronic shutter
Once pressed, the shutter lets light in. Light initiates the production of a picture when it reaches the camera's film.

Fresnel surface
The same size as the finished picture, the aluminium plastic sheet has 200 grooves per inch, distributing light evenly onto the film for better focus.

Processing rollers
The rollers feed the film out of the camera to present the photographer with their image.

Developing picture
The picture is released here, and the image begins to appear on the film. Contrary to popular belief, shaking the film isn't good for development.

© Adrian Mann

Life magazine's cover from 1972 depicts the fascination shown towards Land's invention

© Getty

Closing the shutters on Polaroid

Polaroid continued in business for 50 years, retaining sales even when the technology became outdated. Only at the end of 2008 did the company stop making this product.

The shift of photography from film to digital reduced consumer demand. As technology was advancing, Polaroid decided to stop manufacturing Land Cameras – there were simply not enough people buying them.

However, Land's legacy lives on. Polaroid features are now considered fashionable, and nostalgic photographers continue to enjoy the feeling of a 'real' photograph in their hand. Polaroid Originals recently released the Polaroid Pop, an instant digital camera that embraces old and new technologies.

The Model 95 Land Camera revolutionised photography

Land Cameras were renamed Polaroids after the invention of polarising discs

© Getty

HOW SAFE IS YOUR COMPUTER?

CYBER WARFARE

CRIMINALS SPIES, HACKERS AND VIRUSES: HOW THE BATTLES OF THE FUTURE WILL BE FOUGHT ACROSS THE INTERNET

Words by **Mark Smith**

Hackers could hack into smart homes by gaining access to our smart technology

The world is in the grip of a new age of conflict. Where once ships, planes, tanks and soldiers did battle to further the goals of their own nations, now sophisticated cyber attacks are the new weapons of choice. Countries are using hackers to target power grids, financial markets and government computer systems of rival nations, all with potential results that are every bit as devastating as any bullet or bomb.

The idea of using tech to pilfer information goes back a long way, as far back as 1834, in fact, with two French brothers – the Blanc brothers – who used to earn a living trading in government bonds.

They found a way to get ahead of the competition by bribing a telegraph operator to include deliberate mistakes in messages being transmitted from Paris. This let them get a heads up on financial deals before anyone else did. But as technology got more sophisticated, so did the crimes the crooks were capable of pulling off. However, it wasn't until almost 150 years later that the first person would be charged with a cyber crime.

Back in 1981 a chap called Ian Murphy – imaginatively nicknamed Captain Zap – hacked into US telecoms company AT&T and changed its internal clock to charge off-peak fees to people making peak-time calls. Although he thought he was doing these people a favour by letting them use the phone on the cheap, the company – having lost millions of dollars – and the US government were none too impressed, so he was given 1,000 hours of community service and a fine as punishment.

These days, when you think about what most teenagers get up to with their computers it probably conjures up images of video games or Facebook – not hacking into the computers of the people who put a man on the Moon and built the Space Shuttle.

But that's exactly what 15-year-old Jonathan James decided to do. Installing backdoors – gaps in computer code that allow hackers to easily infiltrate a system – into the US Department of Defense, he was able

In 2019, the FBI issued warrants for the arrest of a Russian hacker group, 'Evil Corp', including Ukrainian hacker Maksim Yakubets

© Getty

to intercept and read thousands of private emails flying all over the place, including some with top-secret information. He then used what he found to steal a piece of NASA software and shut down systems for three weeks.

Cyber attacks had traditionally been carried out by lone criminals – and usually for a variety of reasons. Some like to test their skills against a system and share their successes with others in their shadowy community. Some do it purely for the money, such as Russian hacker group Evil Corp, who are thought to have stolen over $100 million (£77 million) from ordinary people around the world. Others do it for what they see as 'good reasons', such as finding gaps in a company's network so they can take steps to fix it before any serious damage is done.

The first group – the bad guys – are referred to in the hacking community as 'black hat' hackers, while the latter – who think of themselves as the 'good guys' – are called 'white hat' hackers.

Often when a black hat hacker is caught, if they're good enough at what they do, law enforcement or industry will actually give them a job tracking down other hackers and helping to fix flaws in a computer system. But as technology has become more sophisticated, hacking has become a profession with thousands employed by governments as a new tool in their arsenal of war. Often overseen by spy agencies, they're told to carry out attacks on rival countries' infrastructure and steal secret information.

In 2007, in what is believed to have been the first incident of cyber warfare, the Estonian government announced plans to move an old Soviet war memorial, but found itself under a digital assault that sent its banks and government services into meltdown. Russia was blamed, but denied any knowledge.

This evolving threat led to the creation of the US Cyber Command in 2009. Part of the US Air Force, it was placed under the command of General Keith Alexander. It was now official – the cyber threat had gone from kids in bedrooms looking to make a quick buck or prove their smarts to something that was now viewed as a threat to national security.

> "Some like to test their skills against a system"

Alexander's fears were well founded too, with the US accusing China of infiltrating large US corporations to steal their ideas, including Google in 2010, and at least 33 other corporations such as Northrop Grumman – a major weapons manufacturer. The US has also accused Iran, Russia and North Korea of being major state sponsors of cyber attacks. In total, 28 nations are suspected of state-sponsored cyber attacks, including the US.

In many ways these attacks pose more of a threat than conventional warfare. With an invasion, there are signs of military build-up: tanks need building, pilots need training. With cyber attacks, they can come at any time with the press of a button, devastating a whole country's economy or power grid in an instant.

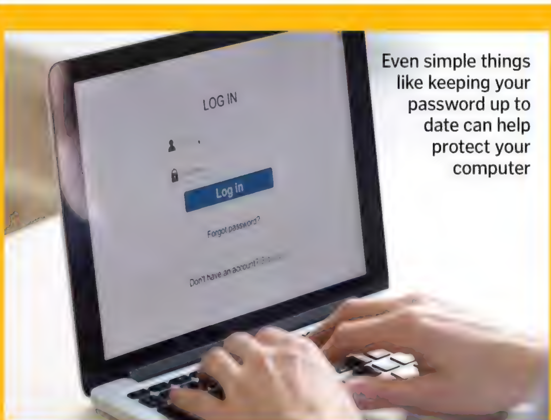
Few attacks have been as devastating or as shadowy as one that took place just a couple of years ago: the WannaCry attack.

It started just like any other morning on 12 May 2017, when at around 08.24 an unsuspecting computer user opened what appeared to be a harmless email. The email contained an attachment which, once opened, downloaded ransomware onto their system. Ransomware is computer code that's been designed to encrypt a system – scrambling all the data on a hard drive – and only unscrambles it when a user gives into the hacker's demands, such as paying money, hence the name ransomware.

If you'd been one of those affected by the WannaCry attack, you'd have logged onto your computer and seen a message asking you for money, with all of your private information such as your pictures, bank records, games, videos – everything – completely scrambled.

It began to spread around the world like wildfire. The first company to report problems was Spanish telecoms giant Telefonica, with multiple staff finding they'd been locked out of their computers.

By 11:00 the UK's National Health Service (NHS) reported problems, with 80 out of 236



Even simple things like keeping your password up to date can help protect your computer

© XXXXXX

Protecting your system from malware

Malware like WannaCry was able to spread because it exploited weaknesses in Windows that Microsoft had already released patches (software updates that fix the weaknesses) for months earlier. But not everyone had downloaded them. Those Windows updates may take a while, but they're there for a reason. Also, installing anti-virus software and a firewall will help to keep the worst malware away. Make sure you download updates for them and run scans regularly – you never know what's lurking on your hard drive.

In addition, just be sensible. Don't open emails from anyone you don't know or click links unless you know the source. Make sure you use strong passwords that are hard to guess and change them often.

Cyber attacks will sometimes try to encrypt your personal data, so make sure you've backed everything up to an external hard drive or the cloud so you don't lose them for good if you do fall foul of a hacker.

DID YOU KNOW? *Around 91 per cent of cyber attacks begin with email phishing, most of them sent via spam emails*

TYPES OF CYBER THREATS

There's a multitude of ways hackers can carry out their attacks

DDOS

You know how slow the internet is when there are too many people on it? A DDoS attack swarms a system with traffic, slowing or completely crashing it. The hacker will often charge a ransom to stop the attack.

PHISHING AND SPEAR PHISHING

Ever had a spam email? Phishing is an attempt to get your bank details or other secret information. Spear phishing is more targeted at you; it may use your name or pretend to be from a friend.

DRIVE BY

These types of attacks happen when a hacker implants dodgy code in a website that you visit. When you open the website it gains access to your computer through your browser.

PASSWORD ATTACK

This is when a hacker uses your passwords to gain entry to your system. They might simply guess your password or use a brute-force attack – a program which tries lots of combinations really quickly.

IP SPOOFING

This is where a hacker disguises the origin of their hack as something trustworthy, so you might think you're visiting your bank's website when it's actually a hacker's fake website stealing your login details.

MALWARE TO WATCH FOR

Hackers have got their own artificial helpers – rogue computer programs called malware

VIRUS

A type of computer code that's been designed to change a system's behaviour, usually to do something nasty. Like a real-life virus, they're also designed to replicate and spread quickly.

SPYWARE

This lurks on your computer, observing the websites you visit or the sensitive information you download. It then transmits that information back to a hacker.

TROJAN

Like the Trojan Horse in Greek history, this is code that's designed to look like something harmless. Once downloaded it gives the hacker access to your system and sensitive files.

RANSOM WARE

This is code that stops your computer operating unless you give the hacker some money to unlock your scrambled information.

WORM

While a virus needs you to download a host – like an infected word document – a worm doesn't. It's a standalone piece of code that gets into your system, often via personal emails.

© Getty

The US power grid was allegedly attacked by Russian hackers in 2018

© Courtesy of the American Public Power Association

Hacker armies are now being employed by governments for cyber warfare

© Getty

hospital trusts having their computers locked out, leading to many of its patients having to be diverted to alternative accident and emergency departments.

The attack didn't stop there. Chinese petrol stations had their payment systems cut off, German railways lost control of their passenger information system and FedEx's logistical operations were disrupted in the United States. French car maker Renault and the Russian Ministry of the Interior were also hit.

Within hours the WannaCry virus had spread to 230,000 computers in 150 countries before being stopped by an analyst who discovered a 'kill switch' that shut it down, but it is to this day regarded as one of the most destructive cyber attacks ever seen.

"Within hours WannaCry had spread to 230,000 computers"

The reason the malware was able to spread so quickly is that it exploited security vulnerabilities in old versions of Microsoft Windows. This vulnerability had allegedly been discovered by US intelligence some months earlier, but instead of warning people they turned it into a cyber weapon called EternalBlue. This cyber weapon was later stolen by a hacker group called the Shadow Brokers, and it's thought it was used to help the malware spread rapidly. The US and UK governments would later single out hackers with links to North Korean intelligence agencies with the attack.

If you take a look around you, you'll probably see a smartphone, tablet, laptop or a smart TV. Maybe there's some other smart tech in your home: a doorbell that links to your phone or a thermostat you can turn up or down by text. On the drive maybe there's a car with all the mod cons like GPS. But every single one of these things could be used as a weapon in a cyber war.

We're surrounded by modern computer technology, and increasingly it's all connected to one another as part of the 'internet of things' – the tech that links smart devices together.

A 2017 briefing by US intelligence claimed connected thermostats, cameras and cookers could all be used either to spy or cause disruption if they were hacked. Only last year, the FBI warned that smart TV speakers, which are designed to listen to our voices, could be hacked for surveillance purposes.

What's clear is that whether it's in our own homes or outside on the virtual battlefield, a conflict between those who want to take control of technology will continue to rage for the foreseeable future.

200 BILLION

Estimated number of connected devices by the end of 2020

6 MONTHS

It typically takes half a year for companies to detect a hacker problem

THE FBI'S ONLINE 'CYBER'S MOST WANTED' LIST FEATURES OVER 100 PEOPLE

3.5 MILLION

Cyber security job vacancies by 2021

4.5 BILLION

Number of records hacked in the first part in 2018

95%

The number of breaches due to human error

24,000

Malicious mobile apps blocked in their thousands every day

CYBER CRIMES ARE HUGELY UNDERREPORTED BECAUSE VICTIMS ARE OFTEN TOO EMBARRASSED

Q&A

FROM CHILD HACKER TO BUG HUNTER

Tommy DeVoss started hacking aged ten and was jailed in 2000 for breaking into military computers. He now earns 'bug bounties' for finding problems in company computer systems

Why did you become a black hat hacker?
At school I would finish my work in ten minutes and spend the rest of the lesson playing on the computer. I was 10 or 11 when I stumbled across a chatroom whose members taught me how to hack – I was just a bored kid doing it for fun. I first got into trouble in high school and was ordered to stay away from computers, but I didn't. With others, I broke into secure government systems and was caught again and spent four years in prison. I was told if I got caught again then I wouldn't get out. In 2016 I discovered bug bounty programs [via the 'HackerOne' organisation] and could return to the hobby I loved, but this time working for good.

Walk us through a typical hacking attack
When hacking a website, I pick a target that has a bug bounty program and spend some time looking at and using it.

Next, I look for interesting places where you might be able to do something like upload files, or where the website tries to fetch data from another website.

I would then try to upload files that could introduce a vulnerability, for example, if there is an option to upload a profile picture. Then I could potentially upload a code execution.

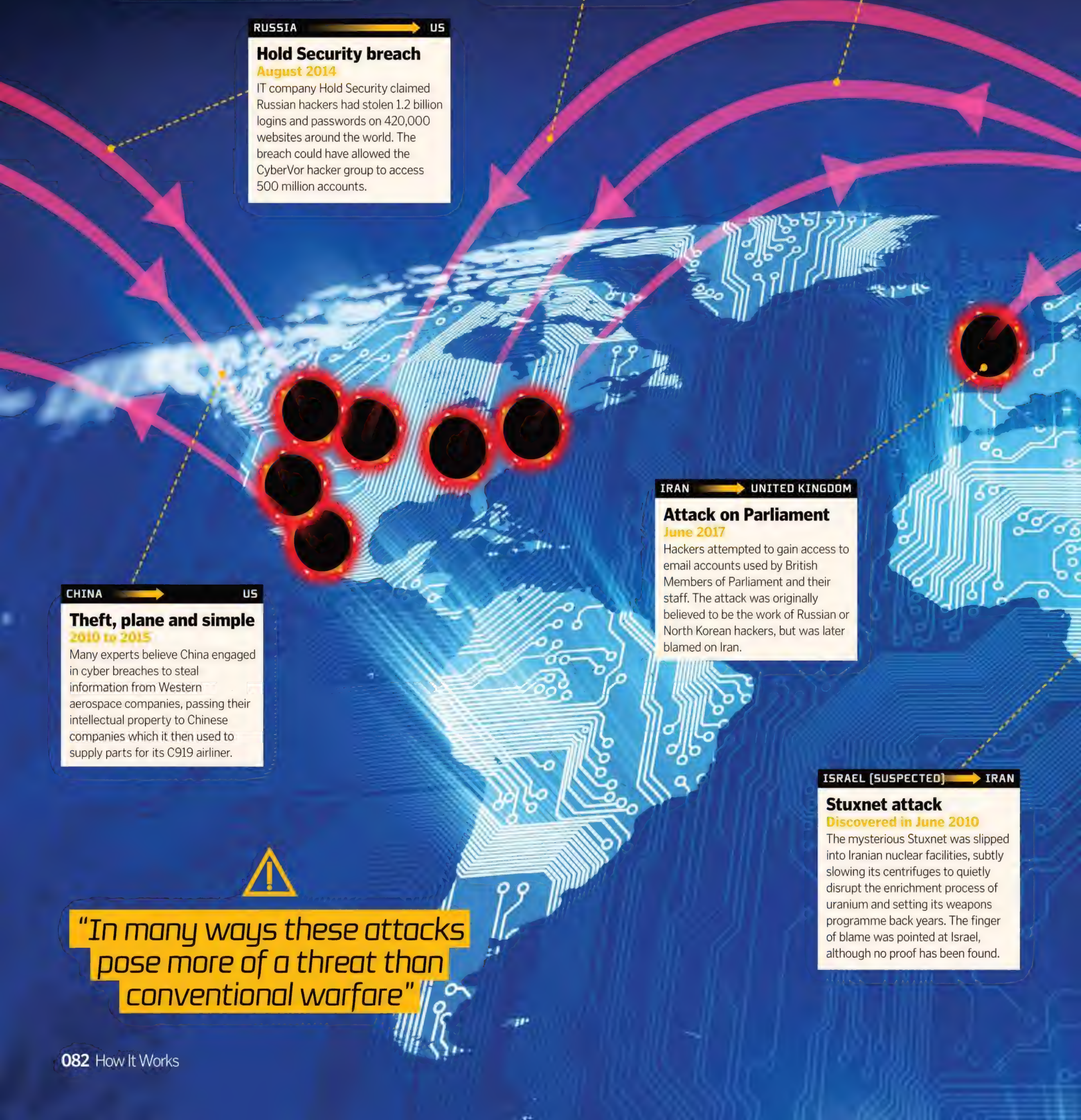
If there is an area like an RSS feed generator, I can see if I can get it to pull data from an internal server that I shouldn't have access to.

How do you see the future of hacking and cyber security developing?
As more things are connected to the internet, we will see more attacks on things in the real world. 25 years ago when I started out, we used to joke about causing real-world damage; it wasn't feasible then, but it is now.

Former hackers doing good are helping to protect us, says Tommy

GLOBAL CYBER ATTACKS

The biggest threats of the last decade couldn't be stopped by fences and checkpoints



RUSSIA → US

LinkedIn breach

5 June 2012

Initially thought to have compromised 6.5 million passwords, in 2016 the company announced it was actually closer to 100 million. Russian hackers were thought to be behind the attack.

RUSSIA → US

Yahoo data breach

2013 and 2014

The internet giant was attacked twice with a total of 3 billion user accounts thought to have been compromised. Investigators suspect hackers tied to the Russian government were to blame.

RUSSIA → US

Hold Security breach

August 2014

IT company Hold Security claimed Russian hackers had stolen 1.2 billion logins and passwords on 420,000 websites around the world. The breach could have allowed the CyberVor hacker group to access 500 million accounts.

IRAN → UNITED KINGDOM

Attack on Parliament

June 2017

Hackers attempted to gain access to email accounts used by British Members of Parliament and their staff. The attack was originally believed to be the work of Russian or North Korean hackers, but was later blamed on Iran.

CHINA → US

Theft, plane and simple

2010 to 2015

Many experts believe China engaged in cyber breaches to steal information from Western aerospace companies, passing their intellectual property to Chinese companies which it then used to supply parts for its C919 airliner.

ISRAEL (SUSPECTED) → IRAN

Stuxnet attack

Discovered in June 2010

The mysterious Stuxnet was slipped into Iranian nuclear facilities, subtly slowing its centrifuges to quietly disrupt the enrichment process of uranium and setting its weapons programme back years. The finger of blame was pointed at Israel, although no proof has been found.

> "In many ways these attacks pose more of a threat than conventional warfare"

The shadowy world of hacker groups

Cyber criminals often reside in online communities, sharing things they've learned and boasting about their 'accomplishments'.

The more hackers that work together, the bigger the feats they're able to pull off, and often they join forces for some shared goal.

One of the most infamous was the hacker group Anonymous. Branding themselves as 'hacktivists' they wore Guy Fawkes masks and claimed to take on the big corporate and government bad guys on behalf of the ordinary people of the world. But since 2015 they have all but disappeared, with fewer hacktivist attacks reported worldwide. Getting involved in political hacking is thought to be one of the reasons many of its members quit.

Hacktivist group Anonymous were fond of wearing Guy Fawkes masks on screen

US → RUSSIA

Power grid strike

June 2019

Last year Russia claimed to have thwarted a US cyber attack on its energy infrastructure. Cyber security experts claim it could have been a retaliatory strike for a Russian intrusion on the US power grid a year earlier.

NORTH KOREA → WORLDWIDE

WannaCry

12 May 2017

The WannaCry epidemic knocked out more than 200,000 computers in 150 countries including the UK, US and Spain. Hackers with ties to North Korea were blamed.

RUSSIA → US

Hold Security breach

August 2014

CHINA → US

Theft, plane and simple

2010 to 2015

RUSSIA → WORLDWIDE

NotPetya/ExPetr

27 June 2017

The costliest worldwide ransom attack in history at an estimated $10 billion (£7.73 billion). The attack began in Ukraine and spread to Europe and the US, with the American and UK governments blaming the Russian military.

US AND UK → JAPAN

Sony PlayStation Network

20 April 2011

A total of 77 million accounts were compromised following an attack by hacker group LulzSec – a splinter group of Anonymous – with an estimated company loss of $171 million while the site was down for a month.

Implanting identity chips

Could these tiny internal mini-computers be the new frontier in contactless identification?

Words by **Scott Dutfield**

How comfortable would you feel about walking around with an implanted chip encrypted with your personal information? Radio-frequency identification (RFID) is not a recent technological revelation, with the technology developed back in the 1970s. They're most widely used today as the chips implanted beneath the skin of our household pets, placed as tags to track products or used in security passcards. However, in recent years there has been a growing trend making its way beneath the skin of human hands.

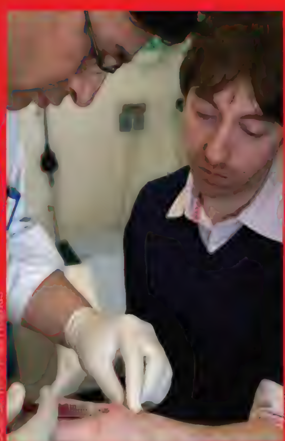
RFID technology has allowed for the development of implantable near-field communication (NFC) chips in humans. Within the implantable capsule, each around the same size as a grain of rice, a tiny microchip stores data, waiting to be deciphered by an external reader. When scanned by the reader the internal chip sends radio waves back to the reader, which is then translated into meaningful data. This data can come in the form of security permissions to RFID-locked doors and contactless payments, and has even been suggested for use in Alzheimer's patients to source medical information.

But how close are we to using this technology in our everyday lives? Well, it's closer than you might think. Back in 2017 a tech company called Three Square Market in the US became the first to offer microchips to its staff as a way to replace the commonly used security cards. 50 workers reportedly underwent the procedure, allowing them not only to open doors but also access computers and even purchase food and drinks.

Inside the RFID chip

How does this tiny device send messages through your skin?

Digital virus



Dr Mark Gasson had his RFID chip implanted back in 2009, before hacking it with a computer virus

The human body is typically well equipped to tackle infection by various viruses thanks to our complex immune system. However, by embedding technology such as RFID chips beneath the skin, could we be inadvertently inviting the possibility of another kind of virus infecting our bodies? With the ability to hold only two kilobytes or so of data, there's not much room to store antivirus or protection software to stop hackers from stealing the chips' entrusted information. Simply standing close to an implanted hand with a reader could collect data, unbeknownst to the owner, a fear also expressed in recent years about contactless card payments. However, back in 2010 a researcher at the University of Reading purposely hacked his implanted RFID chip to house a piece of malware, making him the first human to be infected with a computer virus. Although of course this virus bore no effect on his biological health, the virus could be passed onto the external readers.

Implanting an RFID chip is similar to having a body piercing, tattoo artists being one of the common professions administering the device

Near-field communication chips have become a way for biohackers to have a biologically built-in ID card

Project Cyborg

Taking RFID technology and applying it to human modification became reality in 1998 when British engineer Professor Kevin Warwick and his team at the University of Reading created the first 'cyborg'. Using himself as the first test subject to receive an RFID implant, 'Project Cyborg' saw Warwick undergo a surgery whereby a silicon transponder was placed in his forearm. The newly implanted chip allowed Warwick to walk the halls of the cybernetics department and access doors with ease using the unique signature of the signal emitted by the chip beneath his skin. Taking the implanted technology one step further, in 2002 Warwick underwent a surgery that implanted a 100-electrode array in the nerves of his arm, allowing Warwick to control a wheelchair and an artificial hand. Warwick's controversial experiments paved the way to understanding how the human body responds to implanted technology and its future applications.

Professor Kevin Warwick conducted a series of cybernetic experiments on himself

HERE COME THE SELF-MANAGING ROBOTS

Bristling with modern tech, tools, and a brain to boot – these are the smart machines that could change the way we live

Words by **Mark Smith**

© Wyss Institute at Harvard University

EMERGENCY ROBOT

Steel hero that fears no flames

How do you tackle a blaze that's too ferocious for a human firefighter to go anywhere near? Easy, just send in a robot firefighter instead!

Mitsubishi Heavy Industries in Japan has crafted a team of robo firefighters that combat industrial fires, working together just like human firefighters do.

Each one comes equipped with laser sensors and GPS so they can find their way to the fire. Once there the Hose Extension Robot brings the super-long hosepipe to another robot that has a huge water cannon. It can then unleash its payload and squirt up to 4,000 litres a minute!

It may sound like science fiction, but this team of robots is already up and running, and has been tested at Tokyo's Research Institute of Fire and Disaster.

If robots like this keep proving their worth, how long before TV's Fireman Sam gets a metal replacement?

MITSUBISHI FIREFIGHTER

Weight (kg)	1,600kg
AI rating	3
Agility	1
Cool gadgets	5

Mitsubishi Heavy Industries' firefighting robot is designed to tackle tough industrial blazes

SPACE ROBOT

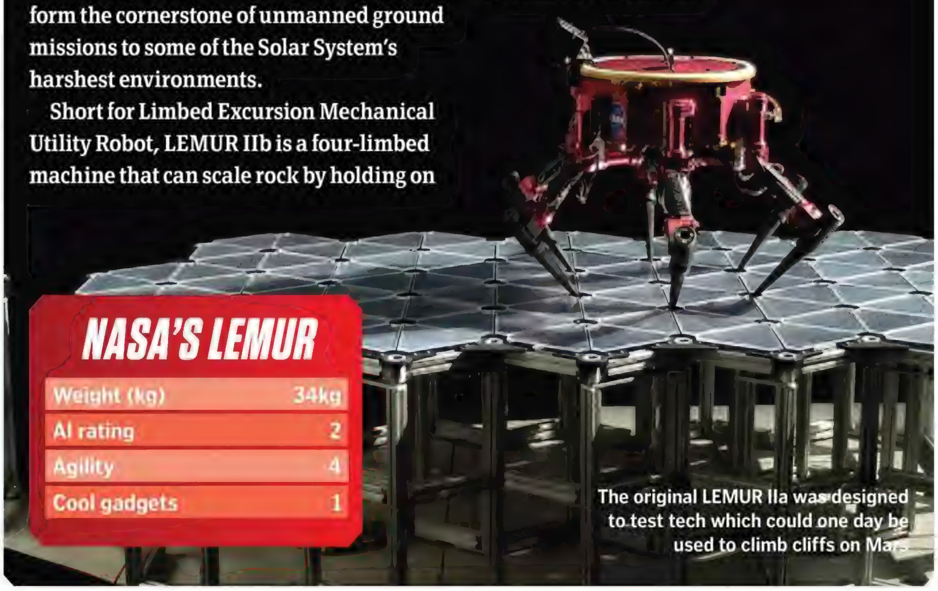
Space robot designed for climbing

Imagine a robot that could scale the craggy cliffs of the Martian wastes? That was what NASA scientists at its Jet Propulsion Laboratory had in mind when they put their LEMUR robot together.

Although this mechanical astronaut is yet to make it into space, the equipment that scientists tested on it could one day form the cornerstone of unmanned ground missions to some of the Solar System's harshest environments.

Short for Limbed Excursion Mechanical Utility Robot, LEMUR IIb is a four-limbed machine that can scale rock by holding on with hundreds of tiny hooks in each of its 16 fingers.

Engineers trialled the robot on a field test in California's Death Valley. During the mission it used artificial intelligence to choose a route up a cliff, managing this without the need to take instructions from its human controllers.



NASA'S LEMUR

Weight (kg)	34kg
AI rating	2
Agility	4
Cool gadgets	1

The original LEMUR IIa was designed to test tech which could one day be used to climb cliffs on Mars

MEDICAL ROBOT

Da Vinci turns robo surgery into an art form

The pressures on the health service are well known. Medical staff are hard to train and are frequently under immense pressure, so what if we could have an unlimited army of artificial medical staff to help them out? The da Vinci robot is controlled by a surgeon via a special panel and comes equipped with surgical arms and a 3D high-definition camera so doctors can view the part of the body being operated on in high detail.

THE DA VINCI ROBOT

Weight (kg)	100kg
AI rating	1
Agility	1
Cool gadgets	5

MILITARY ROBOT

The robot that moves just like we do

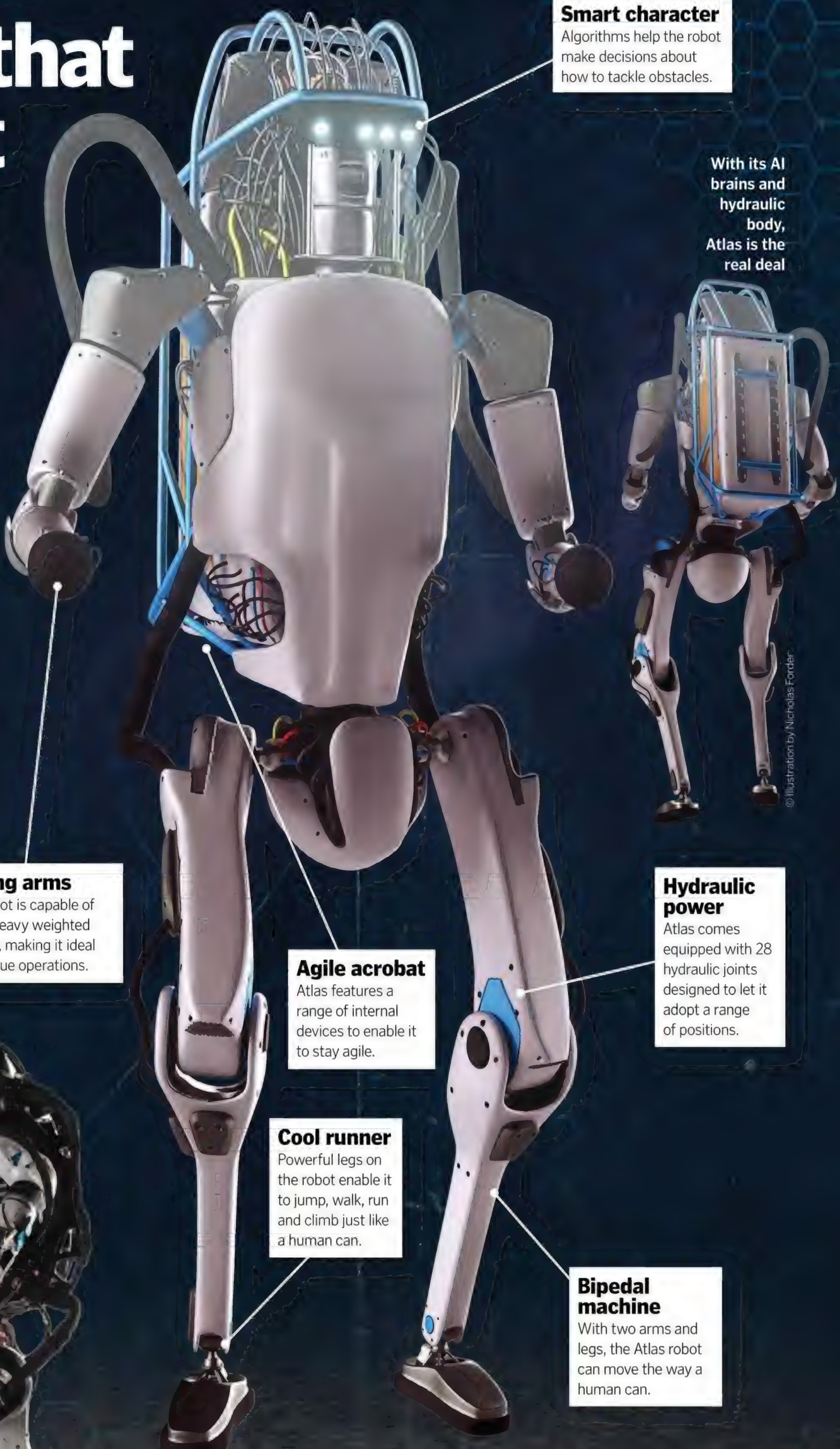
This techno-marvel has arms and legs just like a human that it can use to walk and lift, run and jump. It's agile, strong and tough, and in its most recent tests it could perform a handstand, roll around and do a few jumping twists all without losing its balance.

This truly formidable robot is built around a mobile hydraulic system that packs motors, valves and a compact hydraulic power unit. Its 28 hydraulic joints allow it to perform truly impressive feats of mobility.

But its brains are just as impressive as its brawn. Complex algorithms allow it to make decisions so it can plan out how it's going to traverse specific obstacles.

In terms of construction, Atlas uses 3D-printed parts to give it the strength-to-weight ratio necessary for leaps and somersaults.

Currently being used as a research platform by Boston Dynamics in the US, once fully operational it could be used for search-and-rescue and military operations.



With its AI brains and hydraulic body, Atlas is the real deal

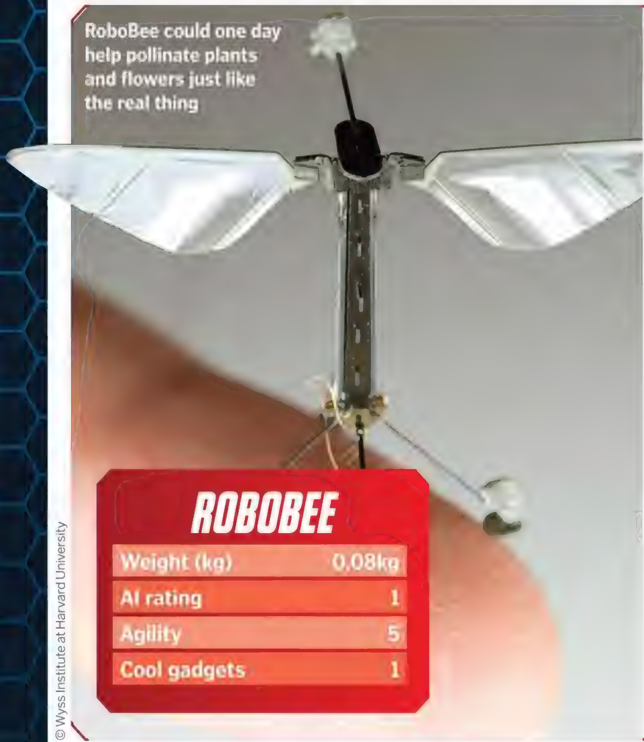
© Illustration by Nicholas Forder

© Boston Dynamic

BOSTON DYNAMICS ATLAS

Weight (kg)	80kg
AI rating	5
Agility	5
Cool gadgets	4

AR ZONE! SCAN HERE



RoboBee could one day help pollinate plants and flowers just like the real thing

ROBOBEE	
Weight (kg)	0.08kg
AI rating	1
Agility	5
Cool gadgets	1

ENVIRO/FARMING ROBOT

RoboBee is ready for action

The robot world is abuzz with excitement about the automated critters being constructed in the United States. Scientists at the Wyss Institute at Harvard University have designed these awesome robotic bees inspired by nature's finest purveyors of honey. Each RoboBee measures about half the size of a paper clip, weighs less than a tenth of a gram and flies using artificial 'muscles' made of materials that contract when a voltage is applied.

They could one day be used in search-and-rescue and even surveillance missions, but with real bee numbers dwindling, it's their potential for pollination that will have scientists most excited.

"They could one day be used in search-and-rescue and even surveillance missions"

HOME HELP ROBOT

A new member of the family?

With the likes of Alexa and Google Home, our homes are increasingly filled with artificial assistants that feel like an important part of the family – but while they can talk to us, they can't actually move. Buddy, however, can.

Designed as a 'social robot', he comes complete with a range of features that enable him to move and interact with everyone.

The kids can play games with him, he can display emotions and can even connect to your smart home devices.

Buddy is designed to be a social robot that can interact with the whole family

BUDDY	
Weight (kg)	7kg
AI rating	4
Agility	3
Cool gadgets	3

Best of the rest

SPOT
Boston Dynamics' Spot has four legs, walks just like a dog and is being used for surveys in the oil and gas industry.

GUNDAM
Japan has built a 20-metre robot. The world's biggest machine of its type weights in at a whopping 25 tonnes.

ROLLBOT
The quirky RollBot can bring toilet paper to those stuck in compromising positions who've run out of loo roll.

KURI
Kuri is designed to react to sound, touch and has a lighting system to let you know what mood it's in.

VYOMMITRA
The Indian Space Research Organisation (ISRO) has unveiled its newest astronaut: a half-humanoid robot.

TRANSPORT

104
How to be a rally driver

AR ZONE!

092 Road to a driverless future

096 Stealthy scout helicopter

AR ZONE!


ANTARCTIC SNOW CRUISER PROJECT
RESEARCH FOUNDATION OF ARMOUR INSTITUTE OF TECHNOLOGY
GOODYEAR

Road to a driverless future

Instead of you driving your car, soon your car could be driving you

Words by **Ailsa Harvey**

They may still be a work in progress, but driverless cars are leading us towards a future where taxi drivers are out of a job and no one holds the role of designated driver on a night out. Car companies like Lexus, BMW and Mercedes are developing this innovative technology in a race to release the first commercial self-driving car.

Until recently, driverless cars were reserved for sci-fi films, but soon the roads could be covered in our 'Batmobile' equivalents. Tesla estimates that its cars, with "full self-driving" capabilities, should be available before the end of next year.

They may still seem an entirely futuristic prospect, but the first research on these vehicles was conducted in around 1500. Admittedly a much simpler concept, limited in possibility and not needing as many safety precautions, Leonardo da Vinci designed a self-propelled cart. This cart is sometimes considered to be the world's first robot as it could move without being pushed or pulled. Steering was set in advance to determine its path – a method not too dissimilar to our future cars.

Much later, in 1933, the development of autopilot systems meant that aircraft used in

"Companies like Lexus, BMW and Mercedes are developing this innovative technology"

Yandex is testing over 100 of its driverless cars in Russia, tracked with manual controls

© Getty


Nissan aims to release its driverless car in 2020. It lets you choose if and when you do the driving

©Nissan

Traffic tamers

Saying goodbye to drivers could, in turn, mean saying goodbye to traffic jams. With instant radio feedback closely following movements ahead, self-driving cars can communicate with each other and will likely have faster reaction times than humans.

Anyone can cause a traffic jam. By simply tapping your brakes, a chain reaction results in a wave of cars behind you being forced to do the same. Scientists have shown that driverless vehicles use their fuel and time more efficiently, improving vehicle flow by around 35 per cent.

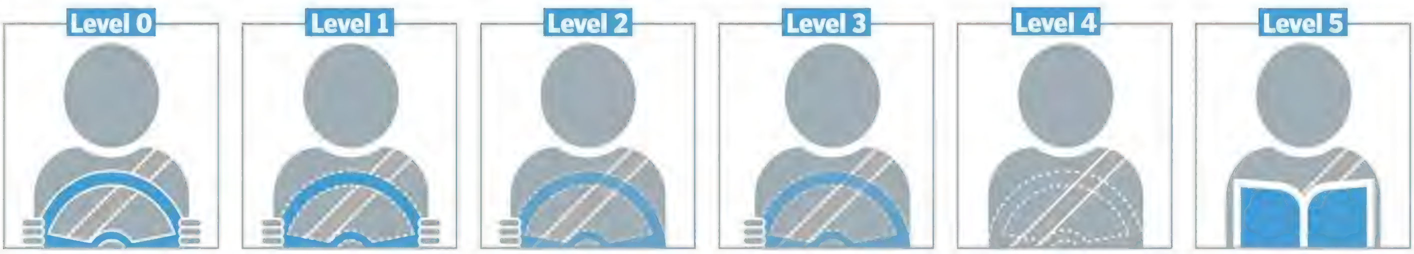
Introducing just a few driverless cars has shown to double the average speed of surrounding vehicles. However, it may take a while before these perks are truly seen, as some believe we need to wait until there is a driverless majority before it has a significant impact on traffic.

This is an example of the interior you could expect inside new driverless cars

© Getty

Driving automation levels

From hands-on to hands-free, these different levels measure how much the car takes control



Fully manual
Like the majority of cars that are currently on the road, this level requires a person to control every aspect of driving.

Driver assistance
In this level, just one aspect of driving is automated. Examples include the steering, speed or controlling the brakes.

Steering and speed
Partial automation means that the car can drive itself. However, at this level someone is still required to monitor driving.

Environment detection
The vehicle starts monitoring the driving environment, but human override is required if the system fails.

High automation
Able to act itself if things go wrong, a level 4 vehicle can perform all driving tasks. However, human override can still be used.

Full automation
Humans aren't needed for any aspect of driving, as the vehicle can do it all. Highly responsive, it can be used in all conditions.

Crucial components

Each part of the car plays a vital role in steering and safety – tasks that are usually carried out by humans

Video cameras
Visual information picked up by cameras is sent to a powerful processor, which continuously scans the images to identify the surroundings.

Central computer
The brain of the car, this receives all the information from other sensors and controls the car's movements.

Lidar (light detection and ranging)
This helps the car see details such as lane markings and pavements, to keep the vehicle driving safely on the right track.

GPS (global positioning system)
This system tells the car its position, accurate to 1.9 metres.

Accident-prevention systems
Alerts are triggered when the radar detects something in the car's blind spot.

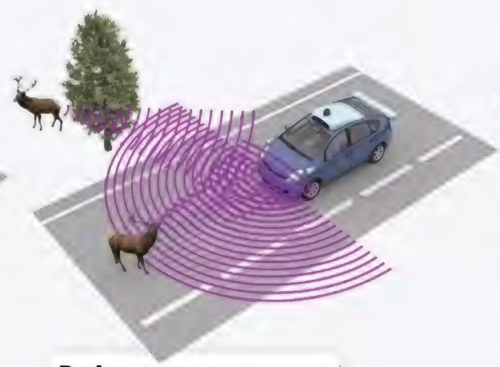
Ultrasonic sensors
Close to the ground, these send out short ultrasonic pulses that detect nearby obstacles and can track how close the curb is.

Radar sensors
Radar detects the location of objects nearby, preventing the car from crashing or stopping too close to other objects.

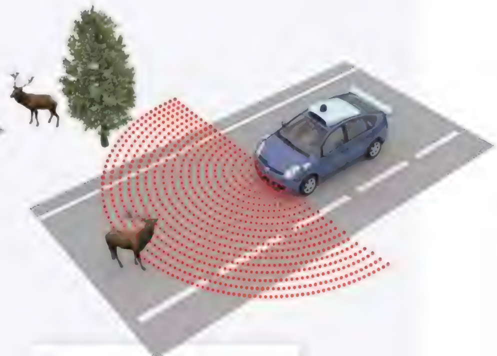
How a driverless car sees

Not only can cars now see, but manufacturers claim they can see better than us

Camera
Detecting lane lines and reading road signs, cameras can only view what the sunlight or headlights light up.



Radar
Beneath the car's metal shell, radar observes surroundings for hundreds of metres. Radio waves bounce off objects, relaying information on the speed and direction.



Lidar
Sending out millions of light pulses each second to reflect off of nearby objects, lidar detects shapes even in the dark.

Deliveries by 'robovan'

The recent advancement in autonomous vehicles means that the parcels you order online could be delivered to your house by robots. That ten-second interaction with a delivery driver, as they hand over the parcel you've been waiting for, may soon be completely unnecessary.

Chinese start-up company Neolix has created a robovan to make this happen. Already in use on public roads, more than 100 of these driverless delivery vehicles have been tested around China. The 'robovans' look like very small vans and are similar in price to a regular car.

Capable of carrying heavy loads and suitable for use in day and night, the vans can be tracked by customers with an app. The only limitation, which the company is currently working on, is how to deliver packages if nobody is in to collect them. Accessible locker systems and walking robots are among the ideas being tested.

Confident that driverless is the future, Neolix has begun mass production of its delivery 'robovans'

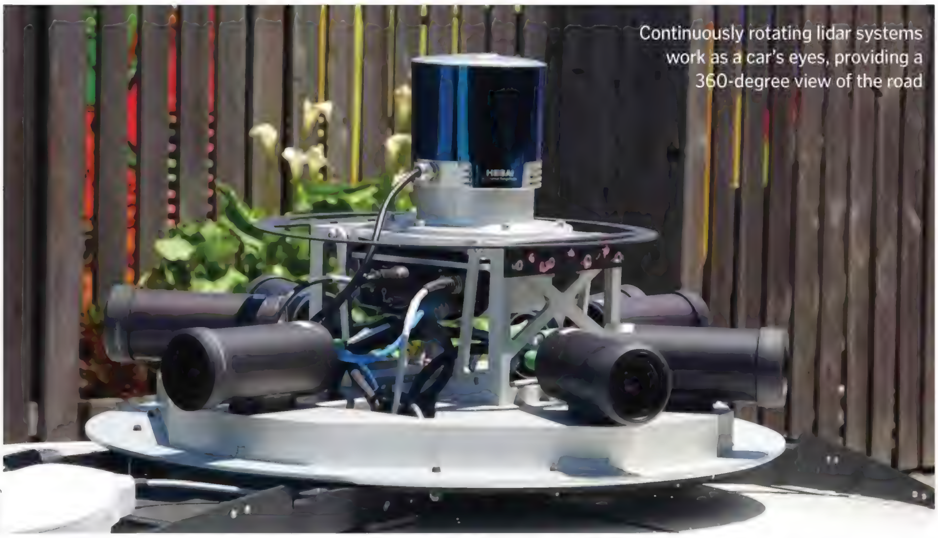
long flights were able to fly without pilots continuously having to control the plane. Sperry Gyroscope Co. was the company that designed the first autopilot prototype, and gyroscopes still play a huge part in driverless vehicle technology.

An important first step in developing the safety of driverless cars arose in 1987, when German engineer Ernst Dickmanns installed cameras and 60 micro-processing modules onto a saloon to enable it to detect other objects on roads. Using them at the front and back of the vehicle, the system was programmed to only focus on relevant objects. Driverless cars use this to ensure that, when on the road, they can spot hazards and prevent crashes.

However, after a pedestrian was killed by a driverless Uber car in 2018, questions were raised into whether this new technology will ever be safe enough. While they hold the potential to prevent accidents caused by human error, if both manual and autonomous cars are using the road at the same time, there is a higher chance of one acting in a way the other doesn't expect, increasing the chances of collisions.

> "Gyroscopes still play a huge part in driverless vehicle technology"

Currently, the closest most have got to testing the transport of tomorrow is using autopilot – a feature that Tesla introduced to its vehicles in 2015. Somewhere between manual and driverless, this hands-free tool for motorway travel was provided as a single software update for drivers. Overnight, customers were able to experience just a taste of the freedom that driverless cars will provide.



Continuously rotating lidar systems work as a car's eyes, providing a 360-degree view of the road

The driverless future is near

39.5% The global increase in the driverless car industry each year

33 million The number of driverless cars expected to be sold annually by 2040

50+ Google owns a large number of self-driving cars currently on the road

90% Fewer traffic fatalities are estimated to occur in the driverless future

40+ Car and car parts manufacturers have announced they are working towards self-driving cars

10 seconds The time it takes for a driver to take back full control of some current self-driving vehicles

257kph The speed reached by a self-driving sports car in testing

The most common accident involving self-driving cars is being hit from behind

A driverless car's AI could decide to risk its passengers' safety to save others outside

Scout and attack helicopters are light and agile for battlefield applications

Super-stealthy scout helicopter

How the S-97 Raider's skilful steering and targeted precision flies circles around its competitors

Words by **Ailsa Harvey**

Most helicopters can be heard approaching overhead as their rotor blades hum a warning. They often cruise over in a flat line, sticking to higher paths in the sky. If this were to happen during a top-secret military mission, it would make the craft an easy target and its cover would be instantly blown. To be stealth-capable, each aspect of standard helicopter technology needs to be fine-tuned, taking tight manoeuvrability, sneakily silent flight and unerring precision to the extreme.

The S-97 Raider, manufactured by Sikorsky, does just this. Aiming to exceed the abilities of other existing helicopters, the S-97 was designed to be untouchable. Its steering capabilities allow it to dodge, whirl and climb the sky at rapid speeds. While these manoeuvres are exhilarating just to observe, they are also deemed critical in combat for the likes of the US army. Confidently following close to the ground – adjusting altitude to match an obstacle-stricken landscape to near perfection – the technology helps to protect and support the troops inside while on crucial scouting missions.

Aircraft components

What key features make the S-97 Raider top of its game?

Fly-by-wire controls
Equipped with an intelligent control system, the pilot's actions will be sent to the flight computer to analyse. Each manoeuvre input is received as an electrical signal for the computer to convert into an action by moving the helicopter's control surfaces. These surfaces can be flaps, slits and elevators that create the required aerodynamicity for the specific move. If a manoeuvre is deemed unsafe by the computer or if it is overloaded it will detect this and stop any unsafe actions.

Retractable landing gear
The wheels are only visible when on the ground, during takeoff and when about to land. Keeping them inside the main body when in flight helps to reduce drag and makes the helicopter more nimble. The wheels retract inwards and the surrounding panels close over, keeping them encased.

Six seated cabin
Inside the cabin there is space for six crew members. With two pilots in the cockpit, a maximum of eight people can board the aircraft.

Top technical manoeuvres

Explore the aircraft's mission-critical aerobatics

PRECISE LOW-SPEED HANDLING
The Raider can perform its sharp turns and tight manoeuvres without having to reach high speeds first. This enables the aircraft to dodge and move more freely when closer to the ground.

LEVEL ACCELERATION
With the ability to increase power without changing flying height, the helicopter is equipped for speedy flights when confined to one height.

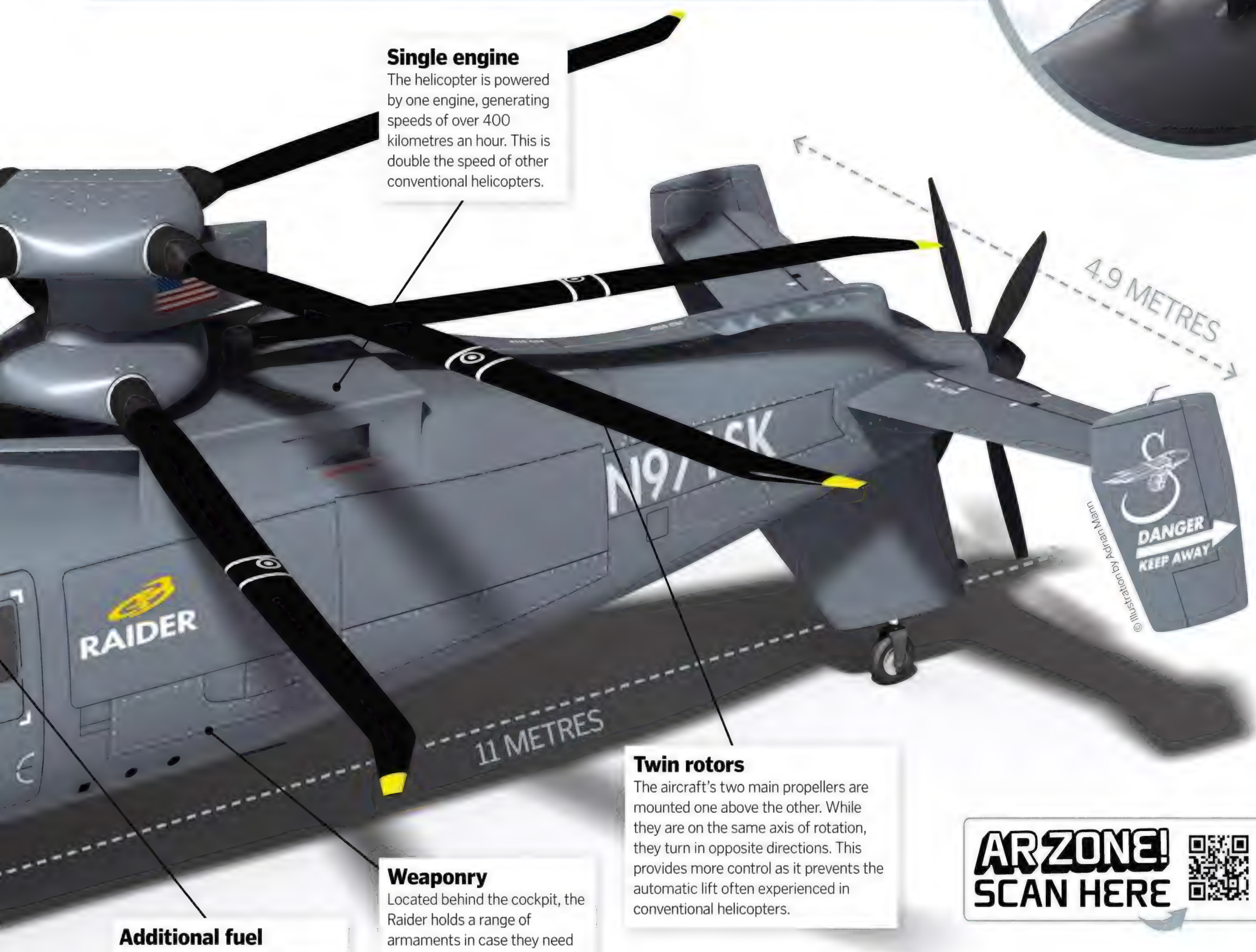
SHARPER TURNING
Compared to its competitors, the S-97 Raider can turn around in just half the distance that it would take in other helicopters. This means that if there was a threat and the aircraft needed to turn around, it could do so quicker for a faster getaway.

HIGH-SPEED CRUISING
Time can be everything in a mission, and the Raider has mechanisms in place to move across battlefields in less time. It shifts power between the propellor and the rotor, reducing exposure time to threats.

Ensuring safety

The S-97 Raider takes pride in its safety, but it hasn't always been smooth flying. In 2017 the helicopter's experimental flight resulted in a crash landing that saw the first S-97 prototype ripped to pieces. Sikorsky put the problem down to a software glitch, which has since been revisited. When the crash occurred in 2017, the two main propellers collided. This double-rotor design helps the helicopter reach record-breaking speeds, and it was concerning that this could be the main safety issue. However, due to it being identified as a software error, the crash is believed to have happened irrespective of the unique design, and the helicopter continues to grace the skies.


The two sets of propellers are perfectly aligned



Single engine
The helicopter is powered by one engine, generating speeds of over 400 kilometres an hour. This is double the speed of other conventional helicopters.

Twin rotors
The aircraft's two main propellers are mounted one above the other. While they are on the same axis of rotation, they turn in opposite directions. This provides more control as it prevents the automatic lift often experienced in conventional helicopters.

Weaponry
Located behind the cockpit, the Raider holds a range of armaments in case they need to be used. These include Hellfire missiles, 7-centimetre rockets, a .50-calibre gun and a 7.62-millimetre gun. This shows the specially designed machine gun for airborne use.

Additional fuel
In case of an unexpected extended mission, an extra internal fuel tank is located on board.

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"They are deemed critical in combat for the likes of the US army"

TARGETED DIVE
Putting the propeller in reverse thrust acts against the aircraft's forward movement. This allows for a slow and controlled dive downwards.

LEVEL DECELERATION
Using a similar deceleration method as in the dive, this simple manoeuvre turns the angle of propeller blades, reversing thrust and slowing down movement. This helps keep accurate focus on any targets.

DOWNWARD HOVER
Pointing the nose down, pilots can keep still in this position. They can also do the same facing upwards. This becomes useful when aiming a sensor towards a target in irregular terrain such as mountains.

PROPELLER DISENGAGEMENT
The pilot has control over when the tail propeller is on and off. While most helicopters need this running at all times, the Raider can shut it down, enabling it to limit noise and approach targets without being detected.


5 tonnes
As the largest Ajax module, Apollo's crane alone weighs the equivalent of 11 horses.
3
Crew members include a driver, commander and gunner.
1500m
Its cannon can hit a target from a distance greater than the length of 14 football pitches.

Digital defenders 21st-century armoured vehicles

Meet the Ajax, a new family of smart army vehicles for modern battlefields

Words by **Ailsa Harvey**

Soldiers have to be quick thinkers, processing data and analysing situations as they play out before coming to an informed and tactical decision. Distributed across a fleet of separate armoured vehicles, crucial information needs to be shared as effectively as possible. Now there is a new family of vehicles aiming to make these processes easier and more efficient during missions: the Ajax family.

Described as the eyes and ears of the British Army, the Ajax armoured fighting vehicles (AFVs) are the first to be fully digitalised. Showing confidence in their performance, the new vehicles have been ordered as a replacement to the CVR(T) (Combat Vehicle Reconnaissance (Tracked)). While its armour is much heavier, Ajax can maintain similar speeds to the CVR(T) fleet, giving them a greater power-to-weight ratio. Corporal Clunn, who is working on the Ajax programme, describes the experience of driving Ajax as "like no other".

"You place a demand on the steering and it follows your direction," Clunn says. "You hit the breaks and the full weight of the vehicle comes to a stop. It feels like you are indestructible."

Perhaps the most groundbreaking feature, however, is its digital technology, bringing army vehicles into the 21st century with the all-weather intelligence and surveillance systems. Integrated with Electronic Architecture, they can detect threats visually and acoustically, instantly responding and acting on these findings far quicker than a human could process. Ajax's digital software is then able to communicate critical data to other vehicles, making army missions smoother and more efficient. Digital maps can be edited within Ajax vehicles and shared across a whole battlegroup in a matter of seconds.

The six Ajax variants are being produced by UK company General Dynamics, who are based in South Wales. While each of the Ajax variants differs slightly in components and primary roles, they all share the core properties and allow all operations to take place from within the armour.

In the future the innovative new software has the ability to continuously improve as digital technology advances – even once the vehicles are built. Working in a similar fashion to a smartphone app update, the platform's internal data can be updated and widely distributed.

Inside General Dynamic's warehouse, where the tanks are put together

© General Dynamics

Q&A

Staff Sergeant Gavin Smith of the Royal Lancers

What does it feel like to be in control of Ajax?
To operate an Ajax from a commander's perspective is like stepping into the future. Crew comfort is better than it has ever been in an armoured fighting vehicle. It gives crews the ability and confidence to operate in all environments and will lead the way on the modern battlefield.

What is the most beneficial feature of Ajax?
The platform's survivability suite – comprising of a collective protection system – is the biggest game changer for me. It enables the crew to operate under armour in all environments, such as a chemical or biological weapon environment. Another part of the survivability system that will give us the edge is the laser warning system, as it gives the platform the ability to detect incoming laser threats from all directions.

How does the digital vehicle compare with others you have used?
Ajax is a complete game changer for the user with its advanced levels of mobility, lethality, survivability, communications and intelligence through its revolutionary Electronic Architecture. The high levels of reliability will allow the platform to operate for longer periods without Combat Service Support (CSS), which legacy platforms can't match. Every platform will allow video, picture and audio to be transmitted from it, too, which is a real battlefield asset.

How will digital platforms improve future army performance?
The modern army is working towards a fully integrated battlespace management system, enabling communications between land, sea and air – Ajax achieves this. The combined awareness systems will give the fighting crew and driver the ability to observe, listen, engage and navigate from within the vehicle while maintaining awareness of their surroundings. Ajax is the future, and with its potential for growth, it should remain at the cutting edge.

The Ajax family

Using a modular system with Ajax at the core, elements can be added to create new variants with specific roles

Ajax
This is the main model at the core of each version. The medium-weight vehicle provides each variant with all-weather intelligence and survivability.

Ares THE TRANSPORTER
Ares is built for reconnaissance purposes: to carry specialist troops safely across battlefields.

Apollo THE REPAIRER
Equipped with a crane system that's put into practise for towing damaged army vehicles, Apollo is also able to repair vehicles, including itself.

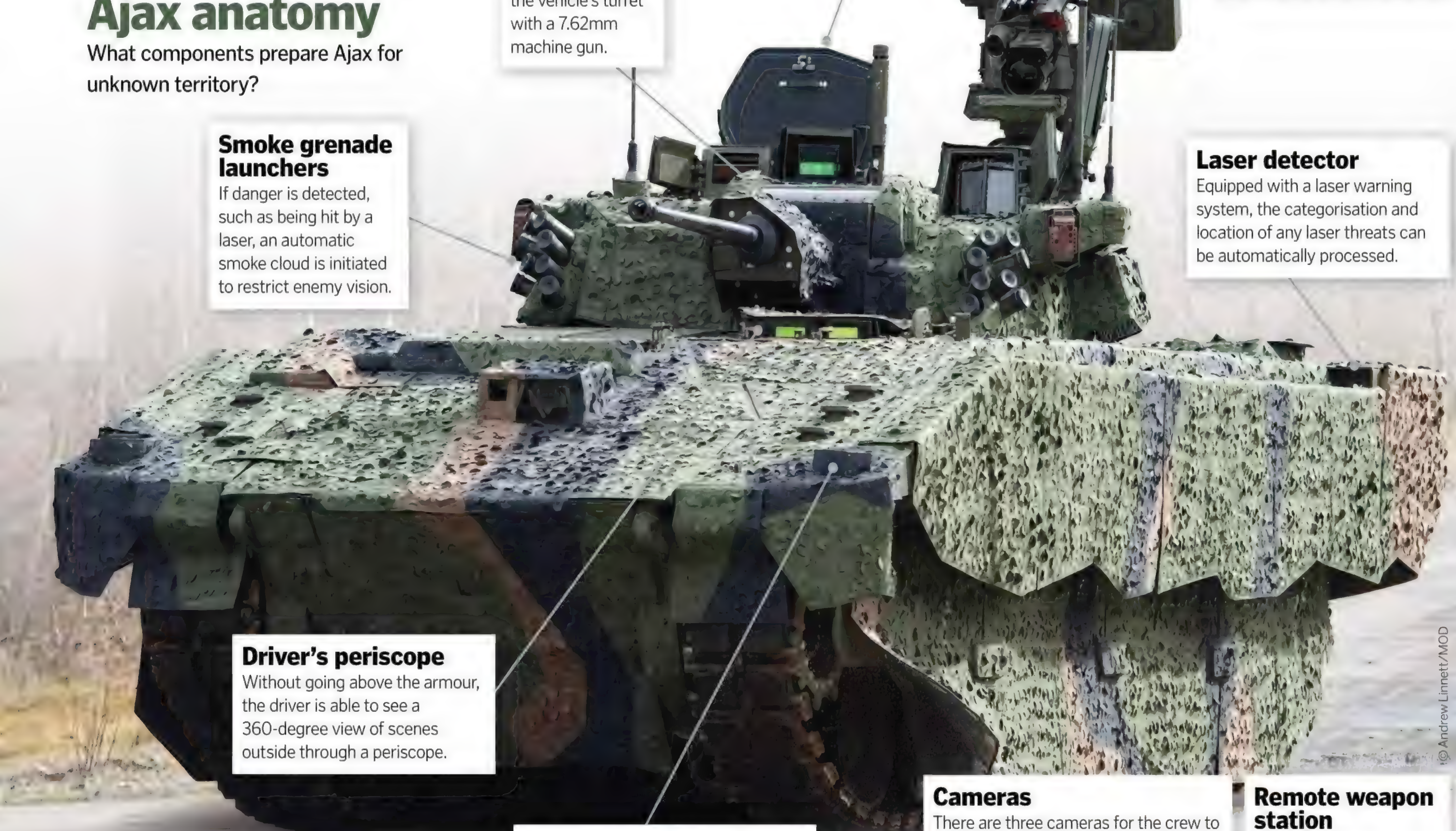
Atlas THE CARRIER
Like Apollo, Atlas includes a recovery package to recover casualty vehicles. This model includes an earth anchor and a pair of winches.

Argus THE LAND-ANALYSER
Assessing the battlefield environment, Argus provides accurate and real-time engineering data, streamed to commanders. This covers both natural and man-made structures.

Athena THE COMMUNICATOR
Essentially serving as mobile battlefield headquarters, Athena creates a protected area to process and manage information from all vehicles. Acting as an information provider, it enables better-informed decisions to be made during missions.

Ajax anatomy

What components prepare Ajax for unknown territory?



Primary sighting system
The main sighting device is placed at the top of the vehicle to give the commander 360-degree views.

Secondary sighting system
The secondary sight is for the gunner, who can spot targets from great distances and accurately engage with them.

Automatic cannon
The 40mm cannon is integrated into the vehicle's turret with a 7.62mm machine gun.

Smoke grenade launchers
If danger is detected, such as being hit by a laser, an automatic smoke cloud is initiated to restrict enemy vision.

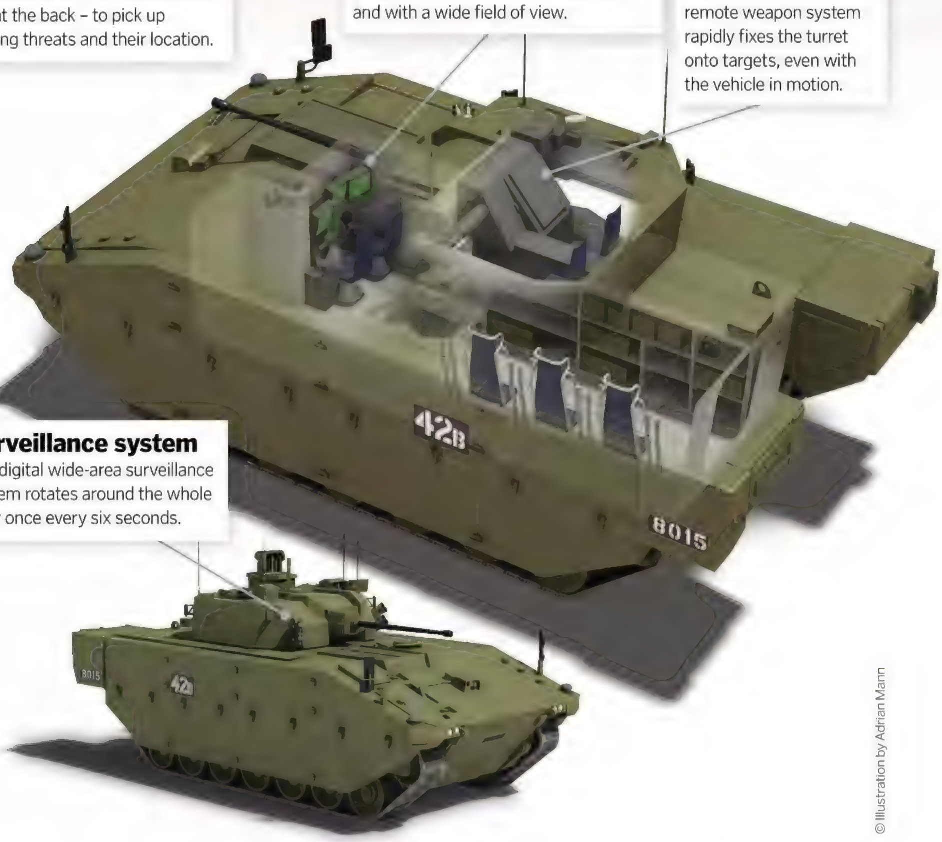
Laser detector
Equipped with a laser warning system, the categorisation and location of any laser threats can be automatically processed.

Driver's periscope
Without going above the armour, the driver is able to see a 360-degree view of scenes outside through a periscope.

Acoustic detectors
Ajax has three 'ears' – two at the front and one at the back – to pick up surrounding threats and their location.

Cameras
There are three cameras for the crew to look at, and eight around the vehicle, all suitable for day and night conditions and with a wide field of view.

Remote weapon station
Working with the stabilisation systems, the remote weapon system rapidly fixes the turret onto targets, even with the vehicle in motion.



Surveillance system
The digital wide-area surveillance system rotates around the whole view once every six seconds.

Pre-field preparation

Before putting AFVs to use, they need to go through rigorous testing to ensure they can tackle difficult terrain, weapon exposure and harsh conditions without degradation. Ajax vehicles were put through trials in Sweden, during which they were subjected to temperatures of -40 degrees and the firing of over 3,500 cannons to test weapon capability.

There is no use having vehicles fit for all circumstances if those driving it aren't completely confident in manoeuvring it. To prepare soldiers, most of the training is done using simulation. This allows the vehicles to be preserved for the battlefield and means that the majority can be put to practical use rather than kept in training grounds. The heavy simulation includes all the digital aspects of the vehicle and even provides realistic sensations of the forces experienced. Around 80 per cent of the training is carried out on these simulators.

Using the simulators, drivers are able to connect to other vehicle devices to practice operating and communicating together as a troop of up to four vehicles.

This Sno-Cat shows how belts rather than tyres spread weight more evenly on snowy surfaces

Enhanced explorers

Over a century has passed since the first Antarctic mission, and there is still so much to explore. Modern-day vehicles have acquired advanced technology that allows an easier transition onto the ice.

Compared to the heavy snow cruiser, today's vehicles are much more compact and lightweight. Modern technology means that vehicles can plan the least dangerous routes to take using GPS and a ground-penetrating radar system. While the cruiser was driving in completely unknown territory, today's radars assess the composition of the ground ahead of the vehicle, so they are less likely to become stuck or stranded.

Unlike Byrd's snow cruiser (see below), most modern Antarctic vehicles have belts rather than tyres, which are more suited to the terrain. Tyre-based vehicles struggle to gain traction on the softer snow, and can sink.

© Alamy

Admiral Byrd before his expedition in 1939

Admiral Byrd's Antarctic Explorer

Words by **Ailsa Harvey**

How did the much-anticipated, 20th century snow cruiser fare in this challenging continent?

Antarctica has been a key scientific research site for centuries. With its vast uninhabited frozen sheet, its conditions make exploration a challenge. However, this has not deterred people from trying.

In 1939, a group of American scientists and engineers chose to focus on this frozen land. Before they could set foot there, they needed the right equipment. For this trip, a monster vehicle was born. Construction was led by Thomas Poulter for the polar explorer Admiral Richard Byrd. Byrd's fourth Antarctic expedition was his most ambitious, as well as the largest.

The scientists would be taken to a playground full of scientific study. What was beneath the ice? Or in the sky? How did the weather compare? The need for both laboratory space and accommodation for several scientists contributed to the size of the cruiser.

Released from its construction bay on 24 October 1939, a 32-kilometre long traffic queue snaked through Chicago as people stopped to observe the cruiser. It was a cross between a bus and a tank: the vehicle was designed to hold all research equipment while tackling travel on the icy terrain. As if its arrival on the isolated Antarctic continent wasn't enough of an entrance, all this was to take place while carrying an entire aeroplane on its roof.

While travelling on roads between Chicago and Boston, a steering fault forced the vehicle into a stream, where it remained for three days. Though a shaky start, it seemed as though almost everything had been thought through and specifically built for Antarctica; from spare tyres in case of emergencies, to its bright red colour to aid visibility.

Hopes were high for Admiral Byrd and the explorers, but some of the cruiser's qualities ultimately let them down. The tyres were cleverly designed to account for a range of snow depth, but were too smooth to cruise through the snow on first contact. Tyres with no tread were believed to succeed best in these conditions, but this was not the case. In fact, better traction was found when driving backwards.

Devastatingly, the cruiser had to be abandoned, as its bulk and lack of manoeuvrability made it difficult to recover. Its exact whereabouts today are unknown.

One of the crew stands beside the cruiser's wheels, giving an idea of the vehicle's scale

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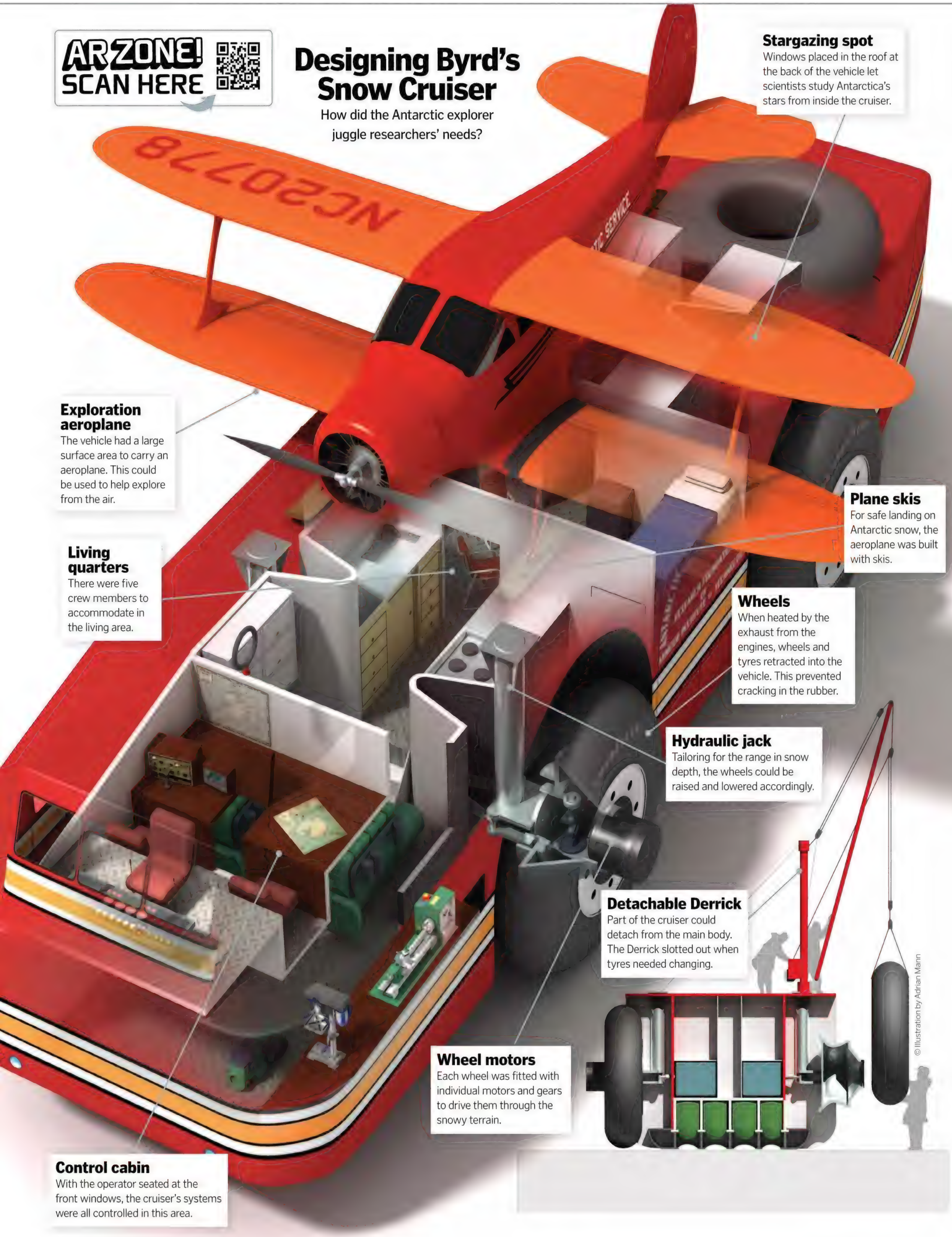
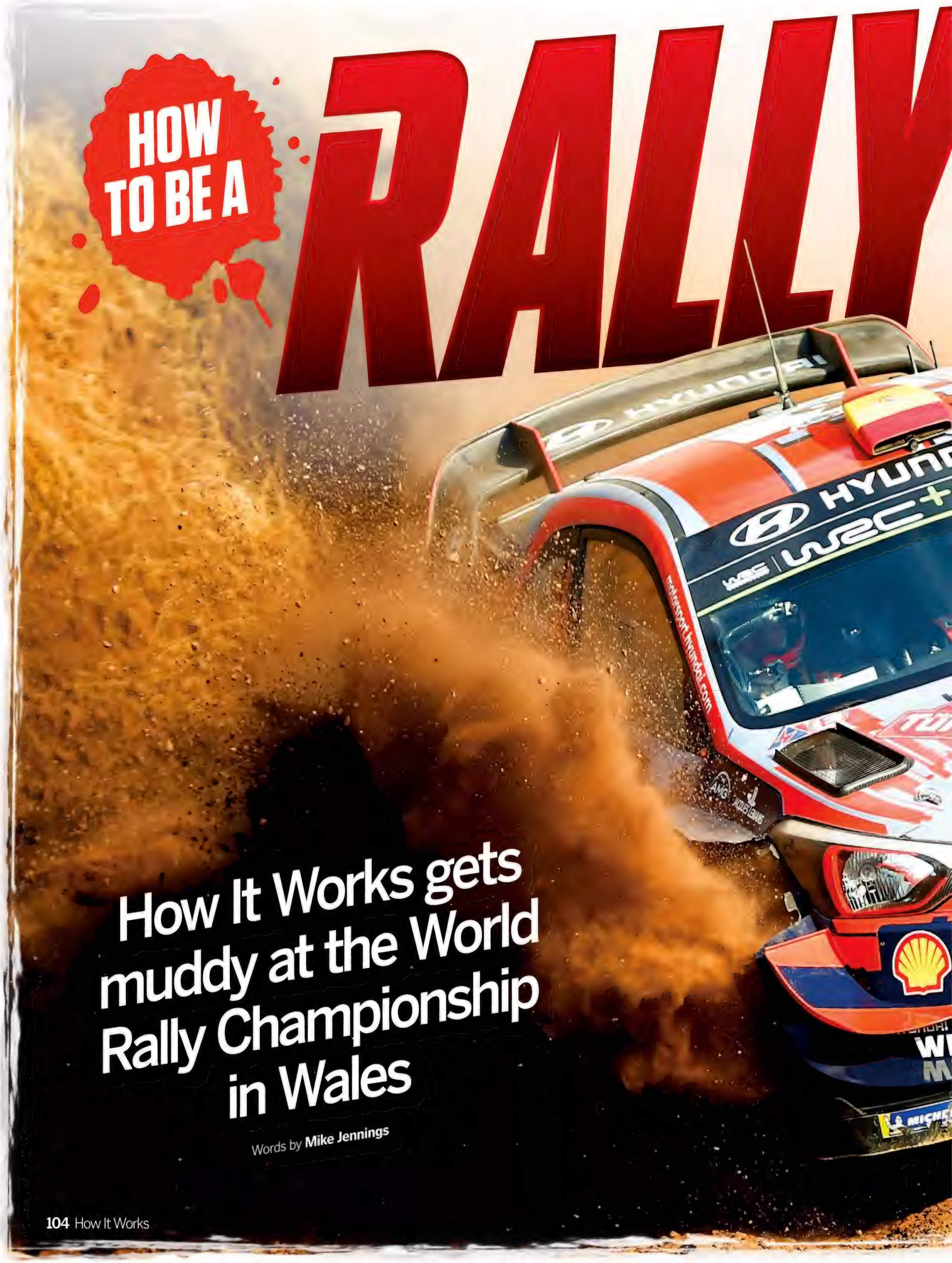
Designing Byrd's Snow Cruiser

How did the Antarctic explorer juggle researchers' needs?





HOW TO BE A RALLY

How It Works gets muddy at the World Rally Championship in Wales

Words by **Mike Jennings**

DRIVER

make a splash on track

Terrain varies massively between each rally stage

No motorsport is as exciting and as adventurous as rally, where drivers tackle remote, rugged terrain in million-pound cars that hit 0-60mph in less than three seconds. It's popular across the world, and no matter where you are the concept is the same: drivers and co-drivers have to complete tough, challenging sections of road in the fastest time possible – and keep their cars in one piece so they can tackle the public roads in between their timed runs.

Drivers are joined by co-drivers, who call out instructions during the stage. It's a tough gig, bellowing notes at more than 100 miles per hour, but it's vital – if a driver has accurate notes, they can attack the road as quickly as possible. Rallying isn't just a partnership between driver and co-driver though – like other motorsports, it's a team game. Rally cars are maintained by teams of expert mechanics at a central service park. Servicing is important because cars get battered and bruised on stages, and engineers can fit new parts to make the cars faster on different types of terrain.

THE WRC EXPLAINED

The World Rally Championship (WRC) is the sport's top level of competition – the rallying equivalent of Formula 1. The 2019 season had 13 events in countries like Mexico, Finland and Turkey, and the 2020 series will be staged across six continents for the first time. The WRC tackles different surfaces too, from the ice of Monte Carlo and the snow of Sweden to the gravel of Argentina and the tarmac of Germany. Teams spend millions to get the most out of their 380-horsepower cars – it's a big deal when manufacturers like Toyota, Citroën and Hyundai can claim that their cars are the toughest. Drivers win points for their overall positions, with those points added together to determine which team has done the best.

Wales Rally GB is the UK's WRC entry, and it takes place all over mid and north Wales. We attended the 2019 event with Citroën to find out how a top team handles the demands of one of the season's toughest events and to experience the magic of WRC for ourselves.

A WELSH ADVENTURE

A WRC round has been held in the UK almost every year since the championship's inception in 1973, and Wales Rally GB can trace its history all the way back to 1932.

It's an important historic event that's been won by every legend of the sport – drivers like Sébastien Loeb, Colin McRae and Richard Burns. It's also one of the toughest gravel events in the WRC, with stages that plunge through forests and run across remote ranges of hills.

Wales Rally GB is one of the year's most daring events

© Red Bull

A team of expert mechanics work flawlessly to keep WRC cars in race-ready condition

© Citroen World Rally Team

263

The number of points achieved by champion Ott Tänak in the 2019 WRC season

Drivers have to travel on public roads in WRC events, not just on fast-paced stages

© Red Bull

Forest tracks are fast, slippery and difficult, with logs lining the roads

© Citroen World Rally Team

The 2019 event was contested by some of the best drivers the WRC has ever seen. The Toyota Yaris squad was led by Ott Tänak, the Estonian who eventually won the 2019 drivers' title. Citroën's lead driver in the C3 was Sébastien Ogier, a modern-day icon who has won six WRC titles. The Hyundai i20 team centred around Thierry Neuville, who is one of the best drivers to never win the title. The UK-based M-Sport Ford team relied on Elfyn Evans in his Fiesta – the WRC's only Welsh driver. The 2019 event was made up of 22 stages that lasted for almost 200 miles across four days – and the drivers also had to tackle hundreds of miles of public roads.

Not all of the crews drive WRC cars. There are several different classes beneath the main WRC drivers: in WRC-2, crews drive more affordable versions of cars like the Fiesta, i20 and C3. There are Junior drivers in smaller vehicles, and more crews piloting older cars like the Subaru Impreza. That's one of the key things about rallying: enthusiastic amateurs can enter the same events as the famous drivers. Rallying isn't restricted to the WRC, either. There are rallies and championships all across the UK for top-level drivers and for those just starting out.

1,800
The number of volunteer marshals who help run Wales Rally GB

Hybrid technology will appear in WRC rallies from 2022 onwards

© Red Bull

The WRC embraces the future

The WRC will be going hybrid in 2022, with new cars that will use conventional petrol power on stages and electric engines for road sections. Pierre Budar is the director of Citroën Racing, and at Wales Rally GB he told us that he sees a huge opportunity to show off hybrid technology. "We have to learn how to use [hybrid]," he explained. "It will be demonstrative with no noise, no emissions, but it needs to bring something to the sport – so we are requesting that we can use this electric power during stages as an extra power source." There are challenges though. "The cost of the car will be difficult," said Budar. "It's a big challenge to produce the same level of performance using this new technology. The hybrid system will weigh around 100 kilograms, so we need to save weight with different designs and materials."

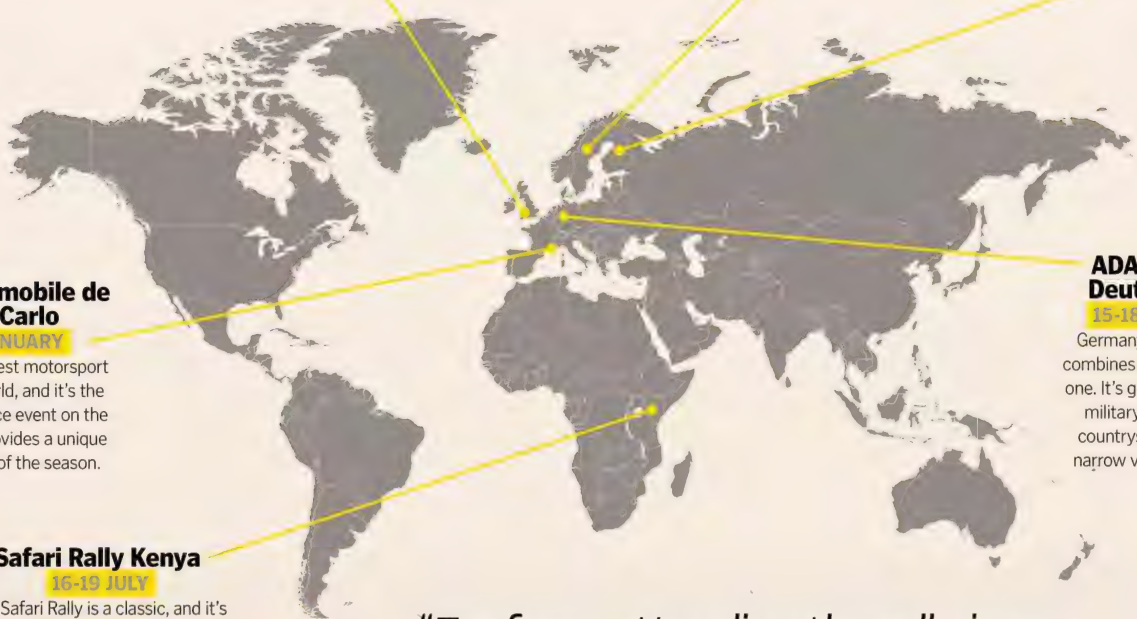
WRC 2020: big changes

The stages are set for a year of fierce competition

Wales Rally GB
29 OCTOBER-1 NOVEMBER
The UK's WRC event is moving later in the year for 2020, which means it's likely to be wetter, muddier and tougher for all of the drivers.

Rally Sweden
13-16 FEBRUARY
The year's only snow event means cars need special tyres – they're kitted out with extra-thin models that are packed with metal studs for extra grip.

Rally Finland
6-9 AUGUST
The fastest event on the calendar uses wide, sweeping roads with hundreds of exciting jumps. It's known as the Gravel Grand Prix for good reason.



Rallye Automobile de Monte Carlo
23-26 JANUARY
It's one of the oldest motorsport events in the world, and it's the only mixed-surface event on the calendar, so it provides a unique test at the start of the season.

ADAC Rallye Deutschland
15-18 OCTOBER
Germany's WRC event combines three rallies into one. It's got stages set on military tank ranges, countryside roads and narrow vineyard tracks.

Safari Rally Kenya
16-19 JULY
The Safari Rally is a classic, and it's back for the first time since 2002. Expect gravel, rough terrain and perhaps some animals on the stages.

"For fans, attending the rally is an adventure of its own – something you don't get in any other motorsport"

A WORLD RALLY CAR EXPLORED

WRC cars are the toughest machines in motorsport – we get hands-on with the Citroën C3

AR ZONE! SCAN HERE

14,208

The hours of WRC content broadcast annually to 155 countries

© Illustration by Nicholas Forder

Caged in 3

A sturdy metal roll cage helps the car keep its shape if it rolls over so drivers stay safe in accidents.

Tyre types 5

Michelin provides rugged, gravel-spec tyres to WRC teams, and drivers can pick between soft and hard tyres with different performance levels.

380 bhp

The amount of horsepower delivered by each WRC car

Breaking point 4

The Citroën C3 WRC has huge brake discs that offer far more stopping power than the road-going version.

Spares and repairs 3

WRC cars have spare tyres, basic components and a toolkit, and drivers often repair their cars on the road.

Suspension tension 4

The rough, bumpy gravel of Wales demands tough suspension – this shock absorber runs all the way up into the car.

© Citroen

© Citroen

© Citroen

© Citroen

Power plant
WRC cars use turbocharged 1.6-litre engines. This huge radiator helps keep them cool, unless it's blocked by leaves, snow or sand!

1 Park life
This is the WRC service park. It's free to visit, and it allows incredible access to teams and drivers.

Like clockwork
Eight expert mechanics are allowed to service WRC cars – the yellow armband means they're part of the team.

2 Aerodynamic
WRC cars like the Citroën C3 go through intense aerodynamic development so the car stays on the road and handles smoothly.

VISITING THE WRC

WRC events follow a similar structure to Wales Rally GB: the service park is assembled in one location – Llandudno in this case – with the teams heading out to tackle stages in the morning and returning at lunchtime and in the evening to service their cars. WRC events have a ceremonial start, usually in a big city, and they usually have a stage in cities or at racing circuits in the evening for easy spectator access. And then, at the end of each event there's the Power Stage – a special run where drivers can earn extra championship points if they're brave enough to really attack the road.

For many fans, attending the rally is an adventure of its own – something you don't get in any other motorsport. There's nothing quite like attending a rally: you wake up early, pulling on waterproofs and wellies before driving through the sunrise to the stunning, atmospheric forests. It's easy to find spots right next to the stages – as long as the marshals say you're in a safe place.

Watching the rally in person is sensational. You hear the cars first, their monster engines echoing around the trees, and then the drivers arrive, hurling their million-pound machines around corners as quickly as possible.

When the stage is over, you can head back to your car and drive to another – and if you're lucky you'll see some of the WRC cars doing the same thing. It's an exciting, surreal experience. Stages are relatively cheap to attend, and the service park is free, so fans can get up close to cars and get pictures with the top drivers.

Rallying is incredibly accessible, and incredibly exciting. There's no other motorsport where powerful racing cars are challenged by so much tough, varied terrain – and few other sports make it so easy to get so close. We're going to dive deeper into the sport here, including exploring the future and finding out what a typical day is like for a champion driver – and we'll see you on the stages when Wales Rally GB returns on 29 October 2020.

Rally cars are based on road cars, but they're beefed up and stripped back to improve performance

© Red Bull

59
The number of crews that contested Wales Rally GB 2019 – only 47 finished

The road to success

WRC cars are based on road-going models – Toyota has the Yaris, while Hyundai uses the i20 and Ford has its Fiesta. However, few of the original cars' parts are used on rally versions – the underlying chassis and overall shape is the same, but that's about it.

Components like the engine, suspension and brakes need to be made more powerful and robust. A roll cage is added to improve safety, and the driver and co-driver need moulded seats, stronger seatbelts, fire extinguishers and an intercom. Spoilers and aggressive aerodynamic features are added. It's vital to save weight too. Virtually every component is either removed or made from lighter materials. WRC car interiors are bare – a prime example of function over form.

Q&A

ARE YOU READY DRIVER?

WRC 2018 eSports champ Jon Armstrong has driven on rally courses across Europe

How do you prepare for driving stages as quickly as possible?

We have to get to the stage by a certain time – sometimes we refuel on the way. We'll pull up a mile before the stage. I'm superstitious so I do everything in the same order – check tyre pressures, put my left glove on before my right glove, put our helmets and seatbelts on and hook up the intercom.

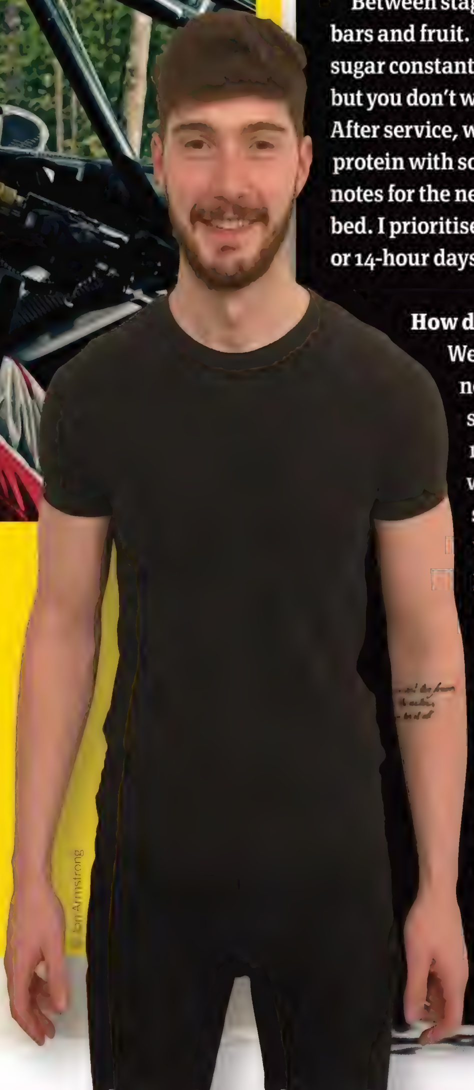
Rally days look very intense – what's your routine like?

We're up early, so we put our fireproof underwear, race suits and boots on straight away. We'll grab breakfast at service – I have something simple, like porridge or an omelette. We talk with our crew about the day ahead, do basic car checks and try and get information about the stage conditions so we can choose which tyres to use.

Between stages we have water, energy bars and fruit. It's important to keep blood sugar constant – you don't want to be tired, but you don't want to spike and crash later. After service, we'll eat a good source of protein with some vegetables. I'll check my notes for the next day, shower and head to bed. I prioritise sleep because these are 12- or 14-hour days – recovery is important.

How do you get ready for events?

We recce the stages to create our notes. We drive the rally twice, slowly, in a road car. We make notes down to every metre so we know how fast to drive the stage and what obstacles we'll encounter. On the first pass I'll call out what the corner looks like, and my co-driver Noel writes it down. On the second pass he'll read back what he's written so we can make finer adjustments. Recce is vital – you need a good balance between caution and speed.



© Jon Armstrong

Jon Armstrong has competed at Wales Rally GB and in Spain, Finland, Portugal and Germany

SWEET LAMB: WELSH ICON

This 32-kilometre challenge is one of the WRC's most famous stages. Here's why it's so special – and so tough

Malfunction at the junction
Drivers head through a junction and into a bumpy, technical section to end the stage. It's narrow and fast – a world-class challenge.

Last-ditch attempt
In 2018, championship contender Thierry Neuville crashed on this simple corner, proving how tough Wales Rally GB can be.

Forest fun
The stage plunges into the Welsh forests here. The roads become narrower and more slippery, because they just don't dry.

Pick up the speed
After this hairpin, drivers head into a faster 60mph section, but tree trunks on the side of the road prove treacherous.

Double trouble
Two hairpin corners run side by side here. It's perfect for watching two monster WRC cars at once!

Hill climbing
This hilltop section consists of jumps and fast corners before a tight hairpin, with loads of drivers regularly caught out.

Bowled over
Sweet Lamb's famous 'bowl' is where cars attack jumps, hairpins and a water splash, so it's a great spot for spectating.

1,028.52 miles
The length of Wales Rally GB 2019, including stages and road sections

HISTORY

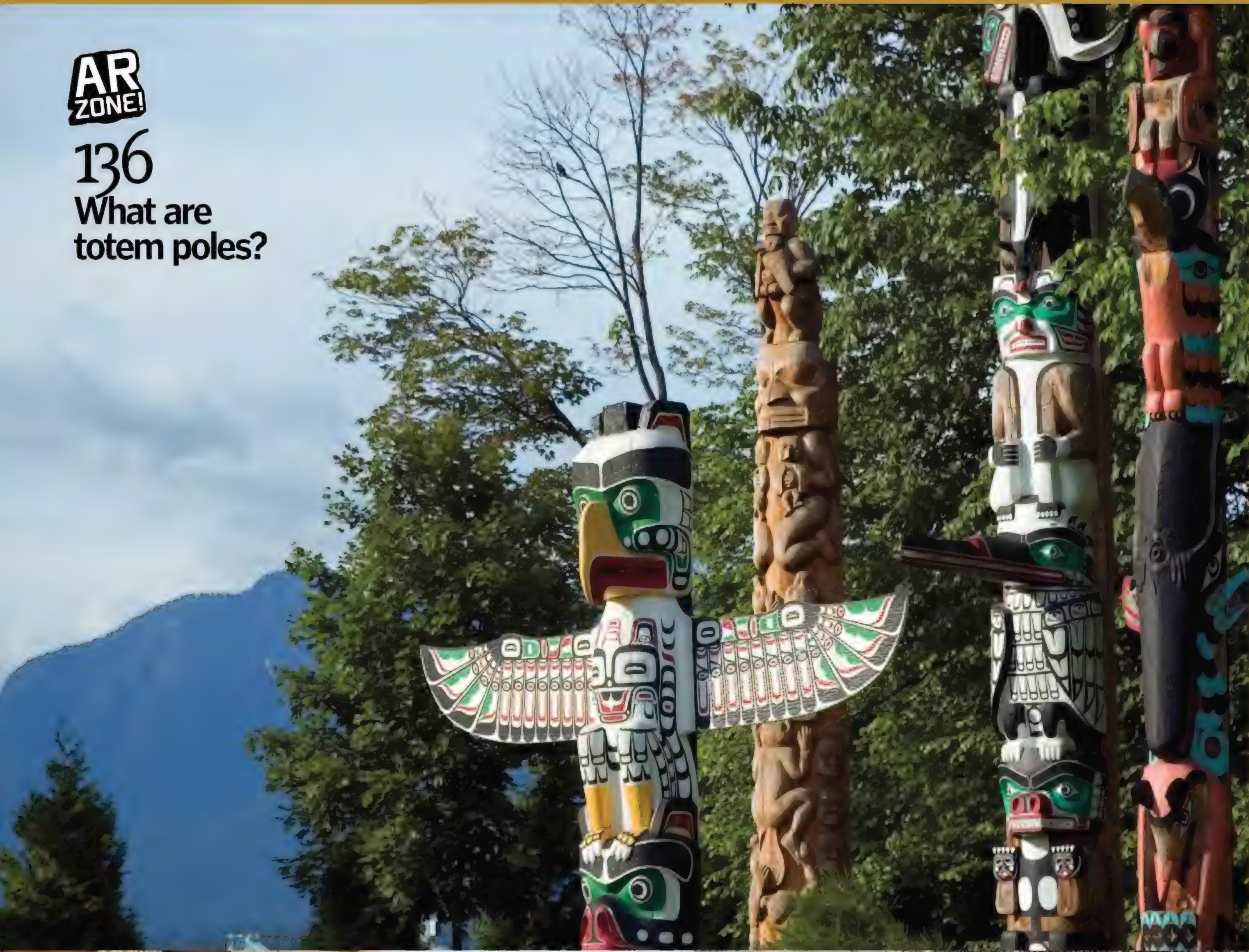
AR ZONE!

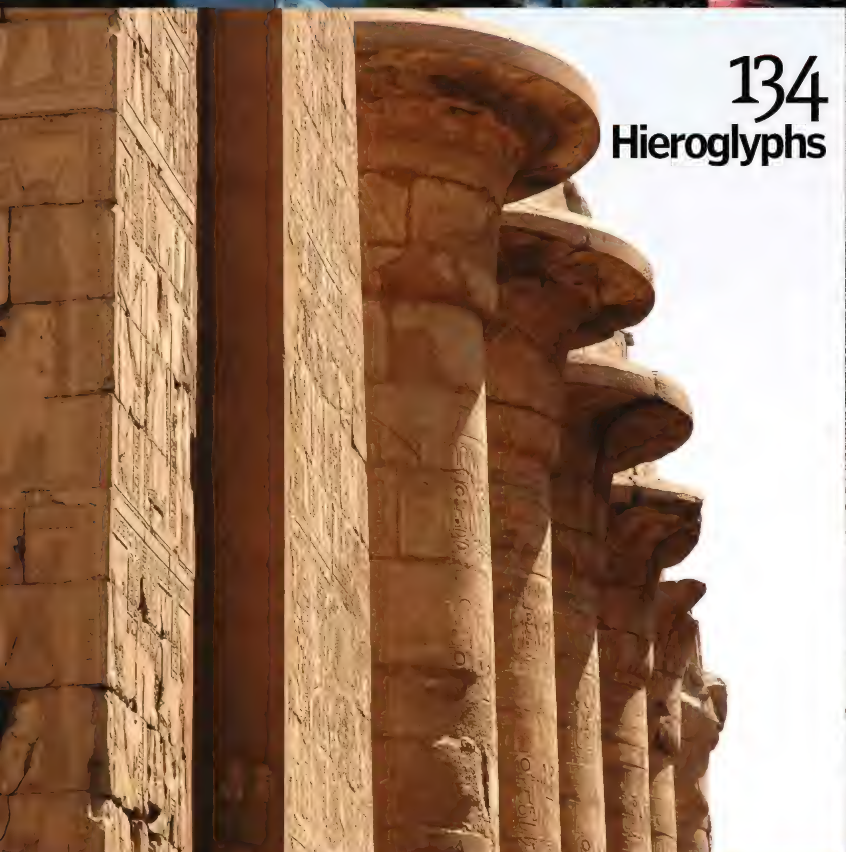
128 Nuclear arms race

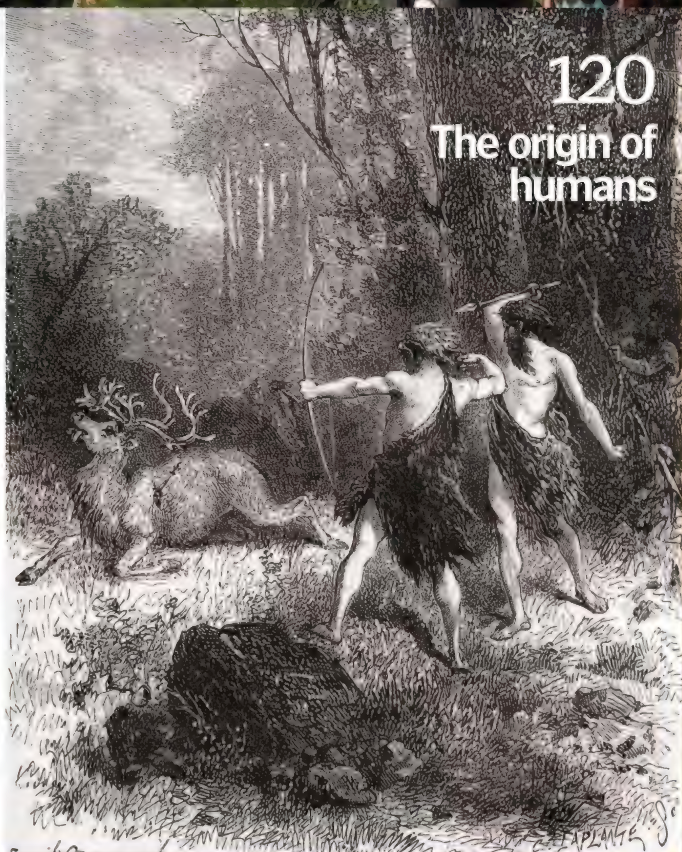
124 Fashion victims

144 How the unsinkable Titanic sank

AR ZONE!







TITANIC
HOW THE 'UNSINKABLE' SHIP SANK

AR ZONE! SCAN HERE

Thousands of people cheered as the world's largest ship was launched, but nobody anticipated its tragic end

Words by **Ailsa Harvey**

The air was buzzing with excitement ahead of the launch of Titanic in 1912. Measuring 269 metres in length, it was the largest and most extravagant ship anyone had ever known. Departing for its maiden voyage, around 2,200 people boarded Titanic along its route from Southampton, England, to New York City, USA. For over 1,500 of them it would be the last trip they ever made.

The passengers were a diverse mix; wealthy holiday-makers and working-class immigrants searching for new opportunities in the land promising the 'American dream'. Due to less space being allocated per person in lower classes, there was a third-class majority on board. Classes were strictly confined to specific areas of the ship.

Titanic was designed to prioritise comfort rather than speed, but was comfort also prioritised over safety? Carrying some of the richest people in the world at that time, it was a huge leap forward in luxury travel. Conditions in second-class cabins were similar to other cruise ships' first class, and Titanic's passengers were provided with gyms, pools, libraries and huge restaurants.

Problems with the vessel occurred from the outset, with a series of accidents and near-misses. While the deaths of those aboard Titanic when it sank are well-documented, the first victims were in fact its builders. It took around 3,000 men to build Titanic over two years. During construction, before the ship had even touched water, eight workers lost their lives, and there were 28 serious accidents recorded.

Further accidents nearly occurred when the ship left Southampton ahead of its maiden voyage. When pulling away from the port, it came within a couple of metres of crashing into another vessel. Many of the passengers were alarmed by this bumpy start to the journey but were unaware of how this event would soon pale into insignificance.

On the whole, passengers were confident that they were safe while confined to this ship, isolated in the ocean. The luxury liner was branded 'unsinkable' by ship designers,

The Titanic in its dock in Belfast, just prior to its fateful maiden voyage

A look at the iceberg

1,600KM
The distance travelled by the iceberg before it hit Titanic

It was one of many floating further south than usual

30 METRES
Its estimated height above water – a fraction of what lay beneath

The iceberg probably calved from a glacier on Greenland's west coast

1.5 MILLION TONS
The iceberg displaced nearly 30 times Titanic's weight in water

The snow that went into creating the iceberg fell 100,000 years ago

"I cannot imagine any condition which would cause a ship to founder"

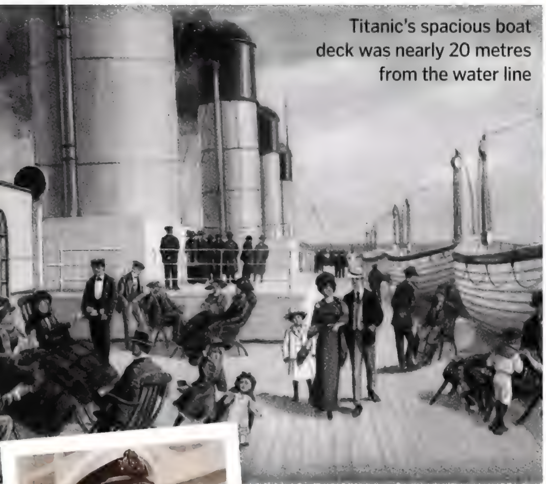
because it was built to stay afloat even with major flooding. But this unsinkable ship would go down – both into the ocean and history.

During the evening of 14 April and into the morning of 15 April in 1912, just four days after setting off, Titanic sank. Two hours and 40 minutes after hitting an iceberg, the ship lay in pieces below the surface of the Atlantic.

Some passengers had always doubted its safety, but other people died because they refused to leave on lifeboats, clinging to the hype of the world's safest ship liner. Why would you voluntarily enter treacherous waters when you're on a ship you've been assured could never sink?

The captain also showed the misplaced confidence held by most in shipbuilding at the time. Before his final voyage he said, "I cannot imagine any condition which would cause a ship to founder. I cannot conceive of any vital disaster happening… modern shipbuilding has gone beyond that."

Unsurprisingly, the disaster raised many questions about what was and wasn't done at the time. Every action taken that fateful night has been analysed and scrutinised during inquiries. The wreckage, which still lies below the water, has been inspected in order to pinpoint where exactly the design failed. How could this tragedy have been prevented?

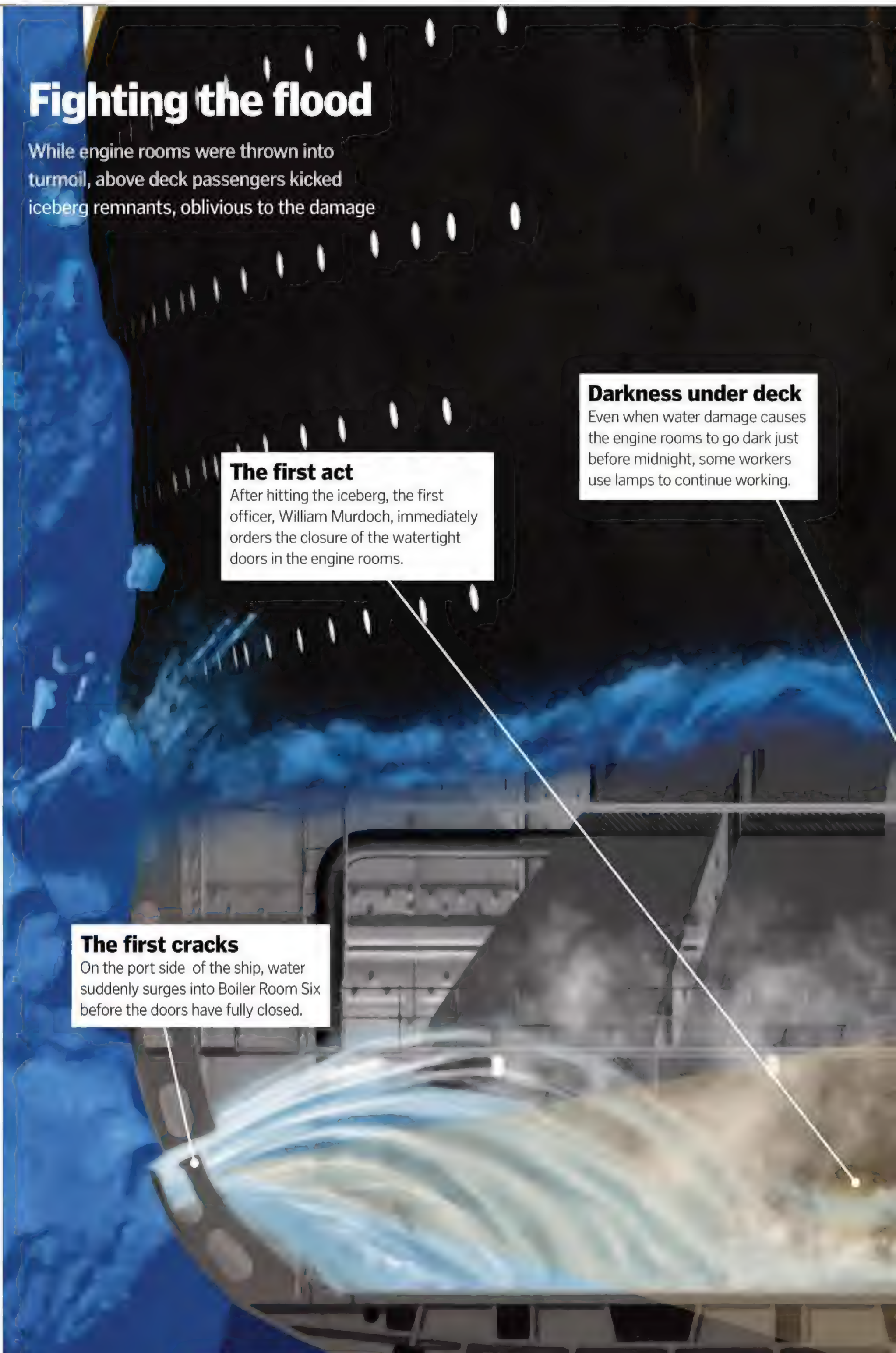


Titanic's spacious boat deck was nearly 20 metres from the water line

© Getty

Fighting the flood

While engine rooms were thrown into turmoil, above deck passengers kicked iceberg remnants, oblivious to the damage



© Wiki

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14 April

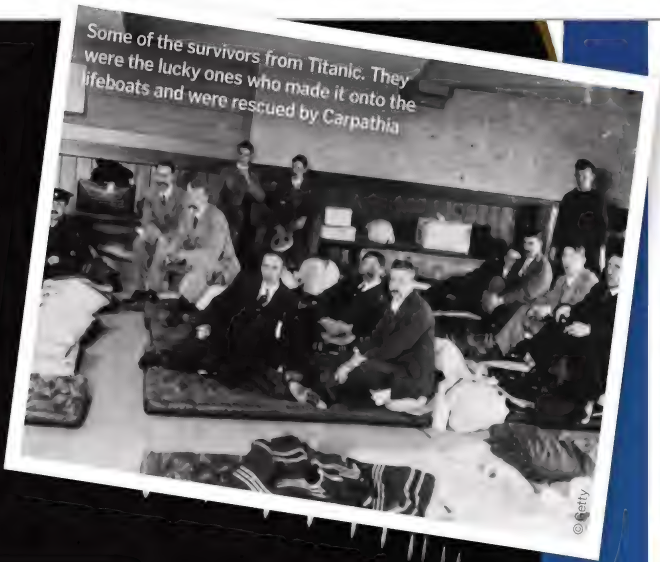
9:20pm
Titanic's captain, Edward John Smith, a very experienced sailor, retires to his cabin for the evening.

10:55pm
A nearby liner warns that it's stopped due to surrounding ice, only to receive an angry response for interrupting wireless operators.

11:00pm
After enjoying a ten-course meal, which will be their 'last supper', most first-class passengers return to their rooms.

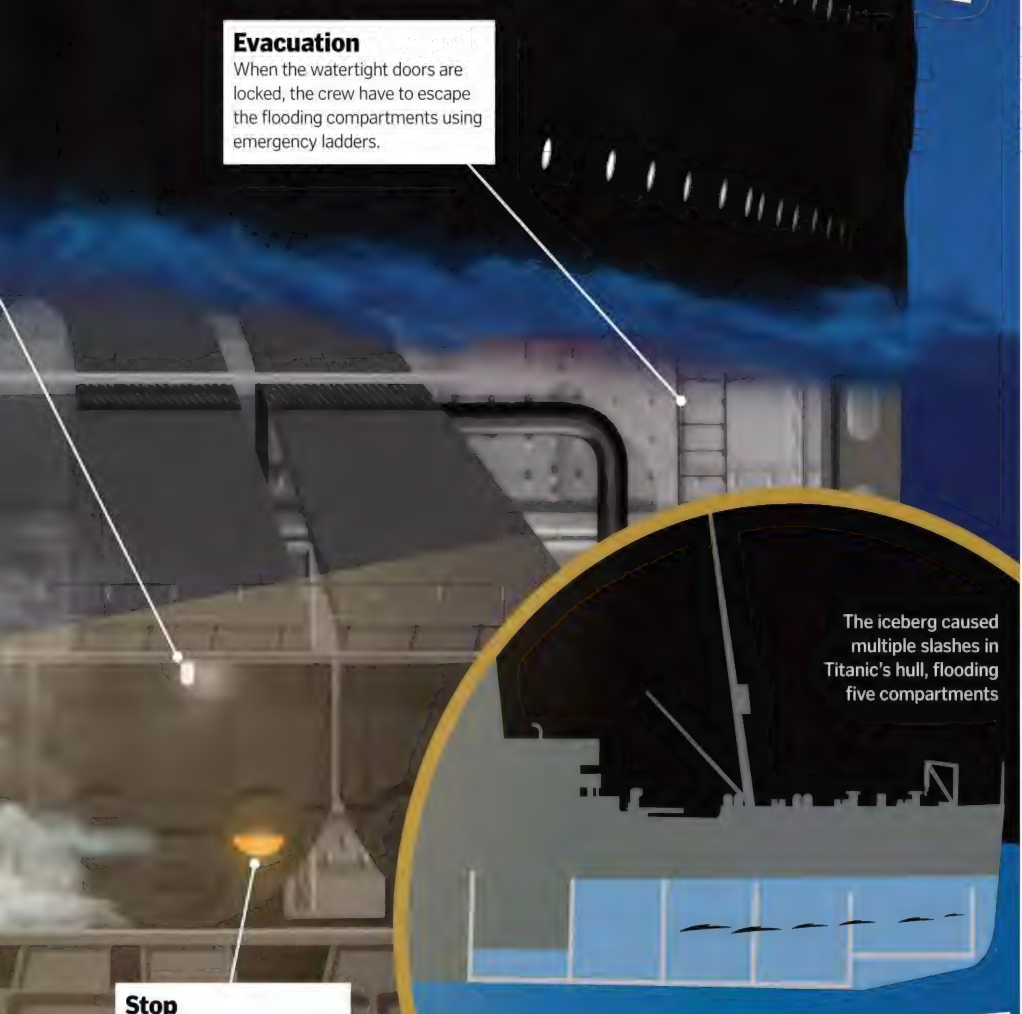
11:30pm
The lookouts notice low-lying mist near where the iceberg is. If they had binoculars with them, this is when they may have spotted it.

11:35pm
Lookout Frederick Fleet spots the iceberg straight ahead. He rings the bell three times and calls to the Bridge.



Some of the survivors from Titanic. They were the lucky ones who made it onto the lifeboats and were rescued by Carpathia

© Getty



© Getty

"Iceberg! Right ahead!"

These were the words yelled by Frederick Fleet, the man who first spotted the icy death trap. As one of two lookouts, alongside Reginald Lee, Fleet was keeping watch when Titanic hit the iceberg.

Spotting danger in the water was made more difficult than usual that night, as the sea was incredibly calm. This reduced the ability to spot objects in the water as no telltale waves were crashing against the iceberg.

On this particular night, the pair stood in the crow's nest, high on the ship's mast, without equipment that could have perhaps saved the many lives lost. Having misplaced the binoculars, it was made impossible to spot the looming ice before it was too late. In the inquiry, Fleet commented that he would have seen the iceberg in time if he'd had the binoculars.

Fleet and Lee's shift ended at midnight and they were replaced by new lookouts. After helping women and children onto lifeboats, they both survived the sinking to tell the story.

How the water spread

After colliding with the iceberg, the front of the ocean liner suffered damage and five of its 16 compartments ruptured. The ship was designed to stay afloat with 12 of its compartments intact, but with only 11 holding the ship together, it wasn't long before the flooded front began to pull the bow of the ship downwards.

The design included a series of emergency doors that would close to prevent water spreading. However, the bulkheads, which were watertight walls separating the compartments, weren't tall enough, and the water swiftly spilled over the top.

Scientists later discovered that a series of thin gashes inflicted on the hull by the iceberg allowed water to stream into the ship, rather than one large slash as was originally believed. It is speculated that the poor quality of the steel used in rivets holding the hull together contributed to Titanic's rapid demise.

© Wiki

11:40pm
First Officer William Murdoch orders engines to be reversed, turning the ship. The right side of the ship scrapes the iceberg.

11:50pm
Water quickly surges into the front sections of the ship, flooding it with around four metres of cold Atlantic water.

15 April

12:00am
The captain is told the ship only has a couple of hours before it sinks. He gives the order to call for help over the radio.

12:05am
An order is given to the crew to uncover the lifeboats and allow only women and children on.

12:20am
Carpathia receives Titanic's distress signals. It goes to assist but is 107 kilometres away. The journey will take three hours.

12:20am
The ship's musicians move from first class to the deck, intending to calm passengers. None of the musicians will survive.

The last communication

Radio logs show the wireless operators' pleas for help during the final hours

CQD
Emergency (an old distress signal).

SOS
Emergency (a new signal that began in 1906)

OM
Old man (a common phrase at the time).

12:15
CQD Titanic 41.44 N 50.24 W.

12:17
CQD CQD SOS Titanic position 41.44 N 50.24 W. Require immediate assistance. Come at once. We struck an iceberg. Sinking.

12:20
Come at once. We have struck a berg. It's CQD OM. Position 41.46 N 50.14 W.

12:25
Carpathia: Shall I tell my captain? Do you require assistance?

12:26
(To Carpathia) Yes. Come quick.

12:30
(To Frankfurt) 41.46 N 50.14 W. Tell your Captain to come to our help. We are on the ice.

12:32
Carpathia: Putting about and heading for you.

12:36
Frankfurt: What is the matter with u?
(To Frankfurt) We have collision with iceberg. Sinking. Please tell Captain to come.
Frankfurt: O.K, will tell.

12:45
(To Olympus) S.O.S.

1:10
(To Olympus) We are in collision with berg. Sinking head down. 41.46 N 50.14 W. Come soon as possible.

1:25-1:27
Coronia: Baltic coming to your assistance.
Olympic: 1:24 am GMT 40.52 N, 61.18 W. Are you steering southerly to meet us?
(To Olympic) We are putting the women off in the boats.

1:30
We are putting the passengers off in small boats.

1:37
Baltic: We are rushing to you.

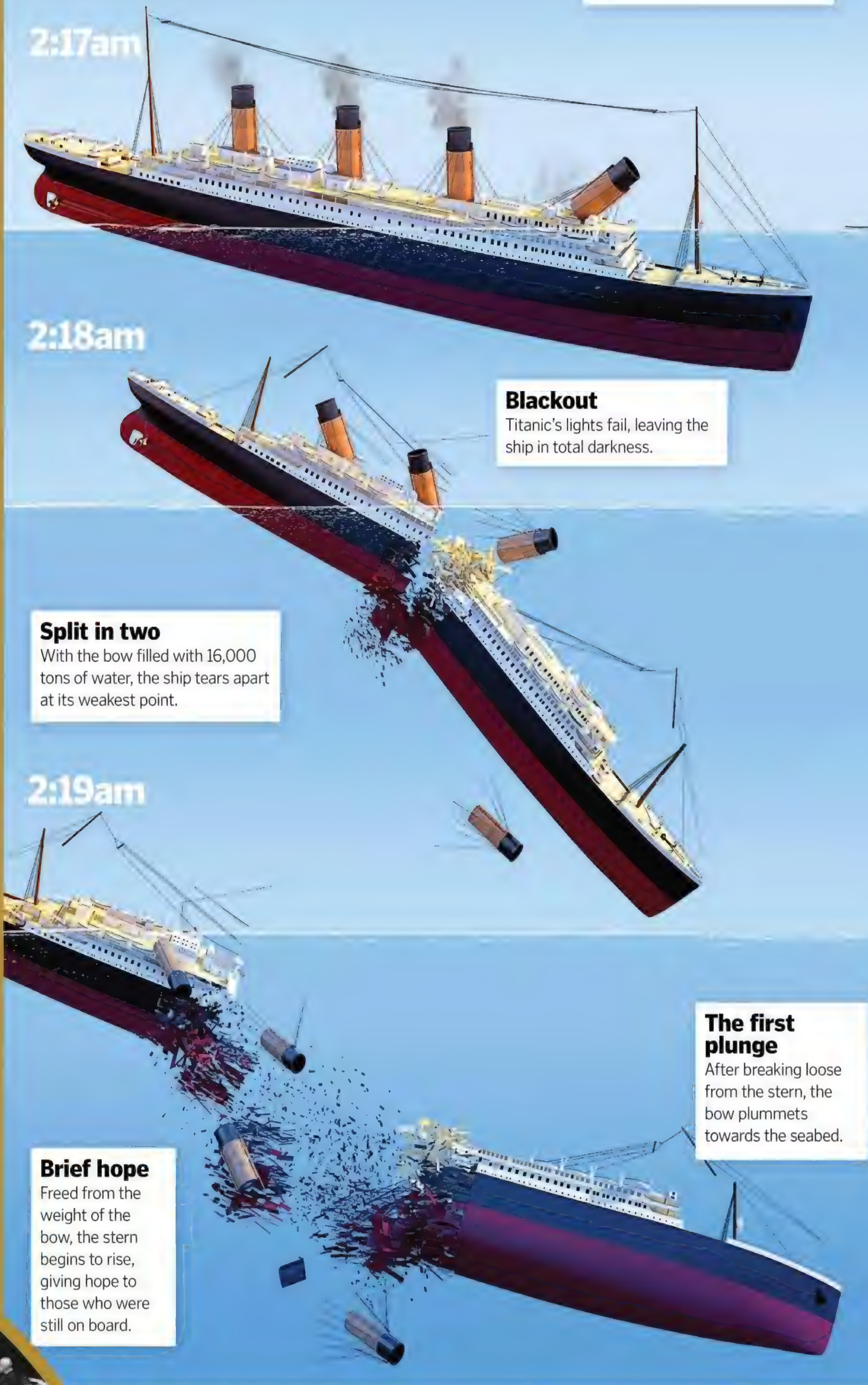
1:45
Come as quickly as possible OM. Engine room is filling up to boilers.

2:17
CQ- (signal stops as the power shuts down).

3:58
Birma: Steamship full speed for you. Shall arrive 6-0 in morning. Hope you are safe. We are only 50 miles now.

The final moments

With 1,500 people still on the ship, the Titanic plunged into the freezing water



Tipping point
As the front of the ship sinks below the water, hundreds of people are washed into the ocean.

Blackout
Titanic's lights fail, leaving the ship in total darkness.

Split in two
With the bow filled with 16,000 tons of water, the ship tears apart at its weakest point.

The first plunge
After breaking loose from the stern, the bow plummets towards the seabed.

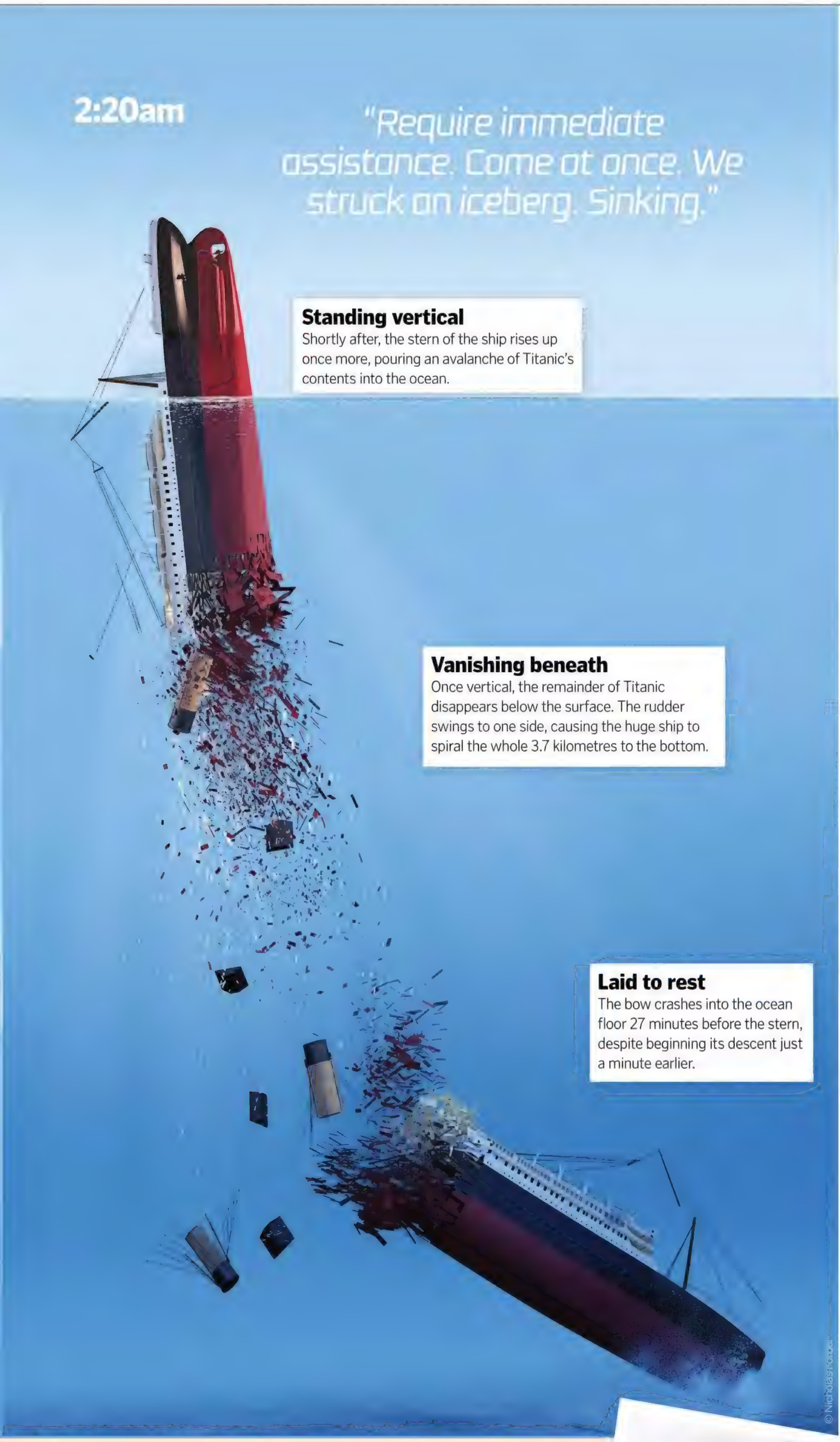
Brief hope
Freed from the weight of the bow, the stern begins to rise, giving hope to those who were still on board.

12:45am
The first of eight distress rockets are fired into the sky by the crew, hoping to draw the attention of nearby ships.

1:00am
The water appears at the base of the Grand Staircase on E Deck, as people continue to load onto the boats.

2:00am
Propellers on the stern are visible above sea level as the front continues to sink further.

One of Titanic's crew speaks at one of the inquests into the disaster



2:20am

"Require immediate assistance. Come at once. We struck an iceberg. Sinking."

Standing vertical
Shortly after, the stern of the ship rises up once more, pouring an avalanche of Titanic's contents into the ocean.

Vanishing beneath
Once vertical, the remainder of Titanic disappears below the surface. The rudder swings to one side, causing the huge ship to spiral the whole 3.7 kilometres to the bottom.

Laid to rest
The bow crashes into the ocean floor 27 minutes before the stern, despite beginning its descent just a minute earlier.

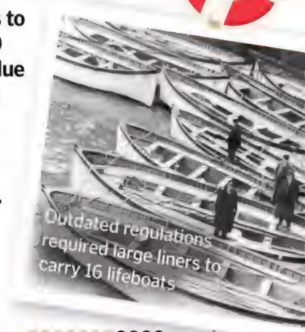
2:17am
The captain relieves the last crew members from their duties. He soon announces that it is "every man for himself".

2:20am
Titanic, having broken in two, finally slips underwater. It claims the lives of 1,500 passengers and crew.

3:30am
The Carpathia arrives to collect the survivors and take them to New York City.

Lacking lifeboats

Titanic had 20 lifeboats to carry 1,178 of the 2,200 people. A lifeboat drill due that day was cancelled, and in a disorderly process boats left half-empty. Only 705 escaped in these boats.



Outdated regulations required large liners to carry 16 lifeboats

© Getty

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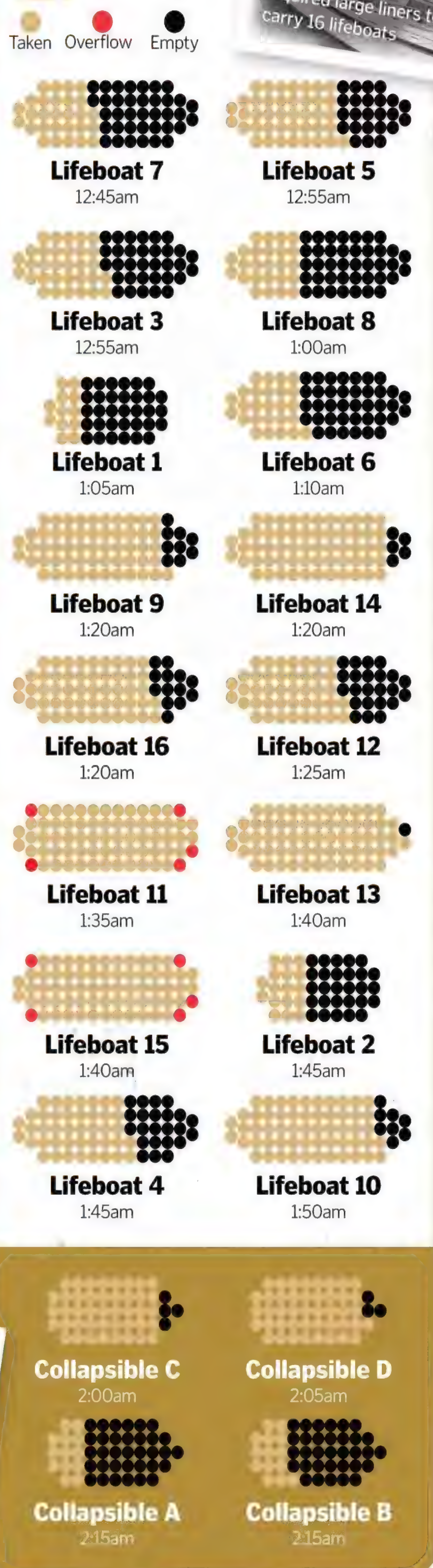
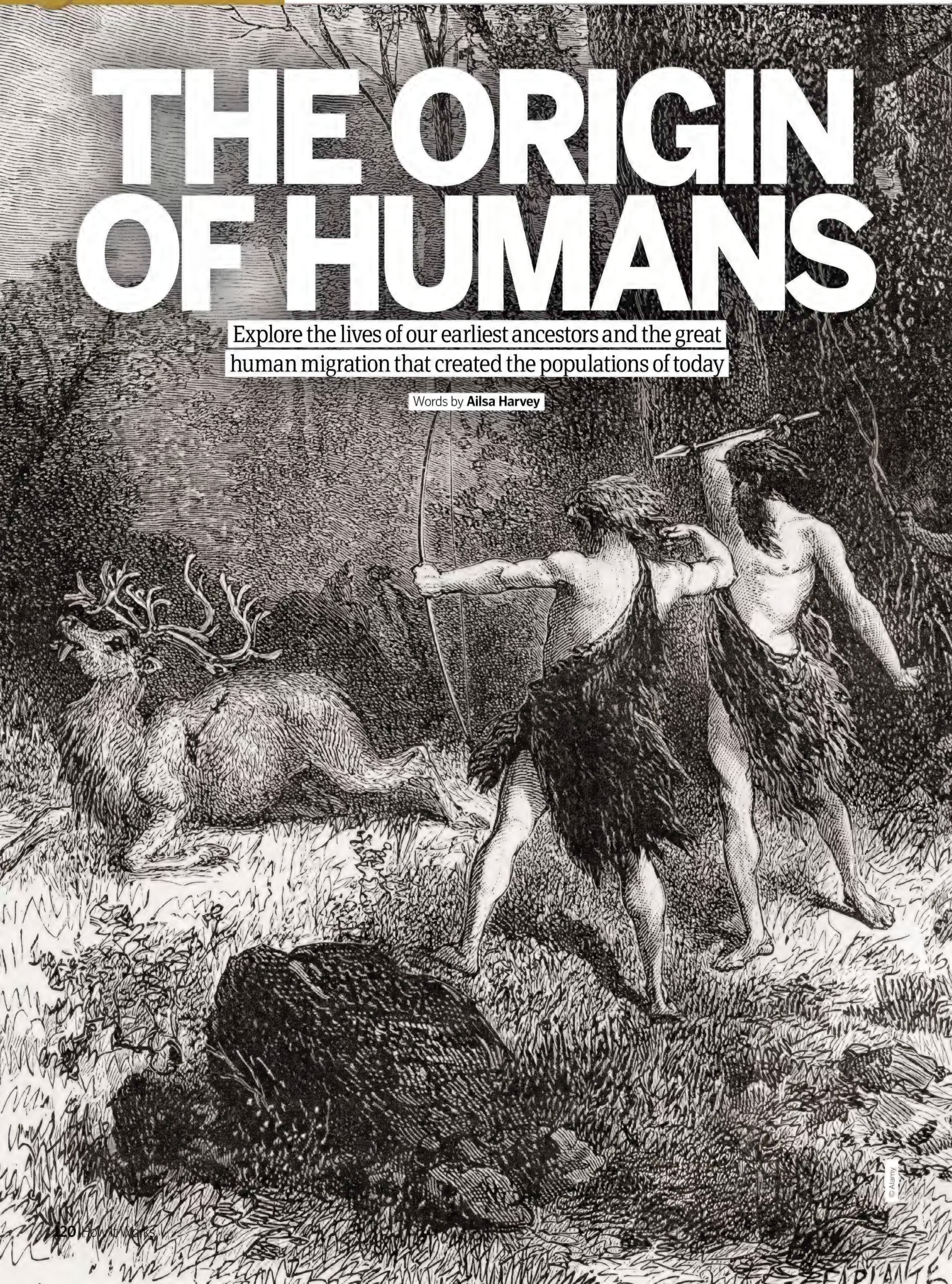


THE ORIGIN OF HUMANS

Explore the lives of our earliest ancestors and the great human migration that created the populations of today

Words by **Ailsa Harvey**



© Alamy

Artist's impression of human species *Homo habilis* hunting with tools

© Science Photo Library

How did we get here? For most of our lives we have some control over what we do and where we go. But the movements and decisions made by those who came thousands of years before us have shaped the evolution of the species we were born into. As a result of early migration, there is now little land on our planet not inhabited by humans. Evolving to suit each location has created differences in our appearance, behaviour and culture.

If you were to jump back in time around 200,000 years, this wouldn't be the case. Despite our differences, every one of us can be traced back to a single population. While other similar human-like species lived on different continents – such as *Homo neanderthalensis* in Europe and *Homo floresiensis* in Asia – our ancestors, the archaic *Homo sapiens* are thought to have come from Africa. As the place where humans first evolved, it is also where our species has spent the majority of its time.

In a land where lions, elephants and wildebeest roamed, early humans were in a constant battle for survival. Some sites, such as Lake Victoria in Kenya, display the animal bones of the dinners they hunted, but their lives weren't easy, with competing carnivores and constant threat from every quarter. Biological studies have linked the evolution of our ancestors, from adopting larger brains to an increase in high-protein diets. Experts think an increase in hunting, as well as the potential of the African landscape to provide high-protein wetland ferns, crustaceans and snails would have contributed to this gradual change.

When the time came for the population to explore other areas, successful migration overseas was made possible by lower sea levels caused by an ice age. The gap between continents was reduced so much so that early humans attempted – and succeeded – to cross. This was likely in the search for suitable food sources, a better climate and space. Humans reached far-away lands, further colonising areas and allowing *Homo sapiens* to expand.

But how are we able to follow and understand this journey that was taken so long ago? Despite the time that has passed, ancient humans left traces of the paths they took: themselves. Studying remains of their bodies, as well as man-made tools and insightful artwork, we are able to understand something of the lives and movements of our ancient ancestors.

As well as providing awareness into successful new settlements, skeletal remains have also played a part in demonstrating many failed attempts at leaving the original homeland. A wave of earlier migrators appears to have paid the ultimate price by trying to leave Africa via the Sahara Desert. When drought returned to the area, resources were scarce and they were left to perish in the dangerously dry lands.

For those that made it out of Africa, they would probably have encountered human-like relatives with different features to *Homo sapiens*. There were nine known 'human species' who roamed the Earth around 300,000 years ago. So how did these variations condense to just the one we have today? Early *Homo sapiens* encountered one of these species in Europe. *Homo neanderthalensis*, otherwise known as the Neanderthals, roamed this area but, as with the other seven species, within a few thousand years of human migration out of Africa, Neanderthals became extinct. Traces of their DNA are carried in many Eurasian people today, proving that our early human ancestors didn't just compete and replace – they also mated, giving rise to new human characteristics.

A simple life

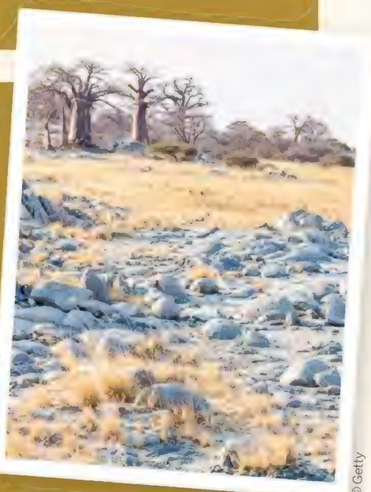
The early humans of Africa lived a life much simpler than ours today. Using the resources available to them, they were able to make tools to hunt, find shelter, start fires and cook food. Using resin from trees almost like a glue, there is evidence of the production of wooden handles and stone knives being whittled together. African settlers are thought to have had an intricate knowledge of the land's plants to use to their advantage.

There are still some people living in the same region who follow a lifestyle not dissimilar to theirs today. The Bushmen in Southern Africa have continued the early hunter-gatherer lifestyle. With open land and available wild food sources limited in today's society, this lifestyle has become far more difficult than the natural ways of those who lived hundreds of thousands of years ago.

Humans' homeland

Recent research involving the study of 1,217 samples of mitochondrial DNA of those living in South Africa has pinpointed a specific area as the origin of humans. Today, if you visit this region of Botswana, just south of the Zambezi River, the land is covered in salt flats. But thousands of years ago, the environment was the perfect habitat for early *Homo sapiens*. In place of the salty, dry plains lay a great lake, holding freshwater that some of the first members of our species could have depended on.

Lake Makgadikgadi and its surrounding land would have been a lush homeland. This body of water existed from 2 million years ago until around 10,000 years ago, covering anywhere from 80,000 to 275,000 square kilometres. This region around the river may have supported human settlement until Africa's rain belt eventually began to shift.



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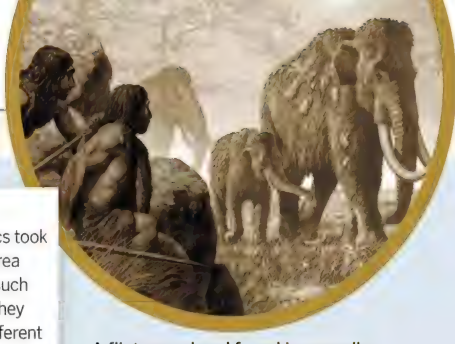
Salt pans in Makgadikgadi are all that remain of the luscious land

The great human migration

Follow the path of our ancestors as they populated the world

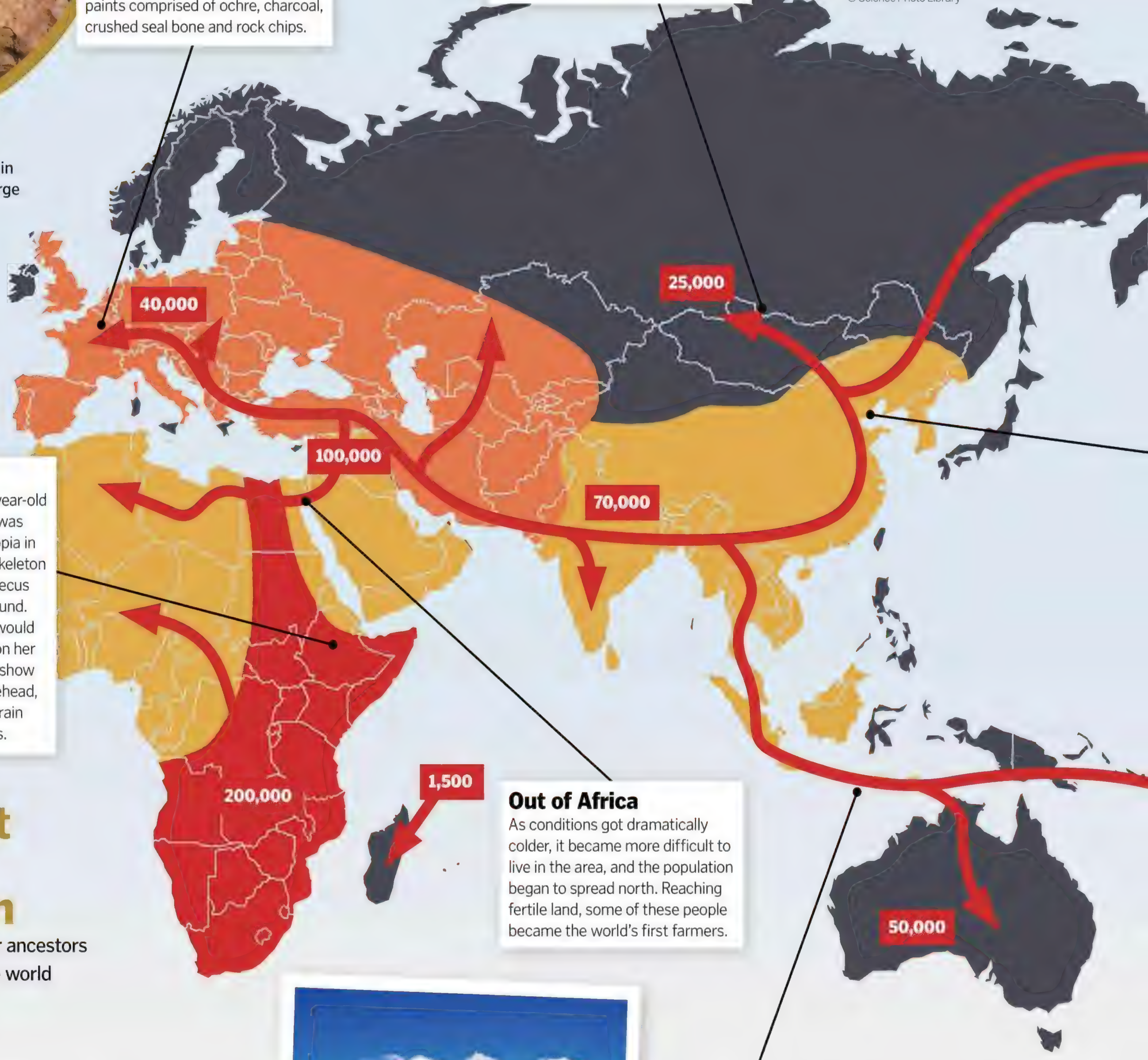
Estimated to be 20,000 years old, cave paintings in Lascaux mainly depict large local animals

Source: Wiki/Prof saxx



A flint arrowhead found in a woolly mammoth bone is evidence of humans' role in their hunting

© Science Photo Library



Ancient artwork

Remnants of our ancestors' artwork can portray aspects of their lifestyles, showing signs of humans beginning to focus on thoughts beyond survival. The famous animal artwork in Lascaux, France, marks the beginning of figurative art. Prehistoric art was created using paints comprised of ochre, charcoal, crushed seal bone and rock chips.

Inland diversion

Migration away from the tropics took humans to Central Asia. This area suited hunters of megafauna, such as woolly mammoths, before they became extinct. From here, different migration patterns saw the species split in a major spread, heading for different reaches of the globe.

Lucy's location

Remains of a 3.2-million-year-old human ancestor species was discovered in Hadar, Ethiopia in 1974. Named 'Lucy', her skeleton was the first Australopithecus afarensis skeleton ever found. Recreations of what she would have looked like – based on her skull and others nearby – show her to have had a low forehead, wide cheekbones and a brain the size of a chimpanzee's.

Out of Africa

As conditions got dramatically colder, it became more difficult to live in the area, and the population began to spread north. Reaching fertile land, some of these people became the world's first farmers.

After sea levels rose, humans living in Australia evolved and adapted to the unique land and ecosystem

Sailing the seas

Crossing the ocean from Asia to Australia, humans discovered a large new continent. It is unclear whether humans crossed in one planned wave or whether multiple trips were made over time, but the journey is thought to have been planned in order to result in enough people on the island to keep a new population going. While the area of ocean separating the lands was shorter when this migration occurred, the journey would still have come as a challenge, navigating large stretches of water on their handmade boats.

Human timeline

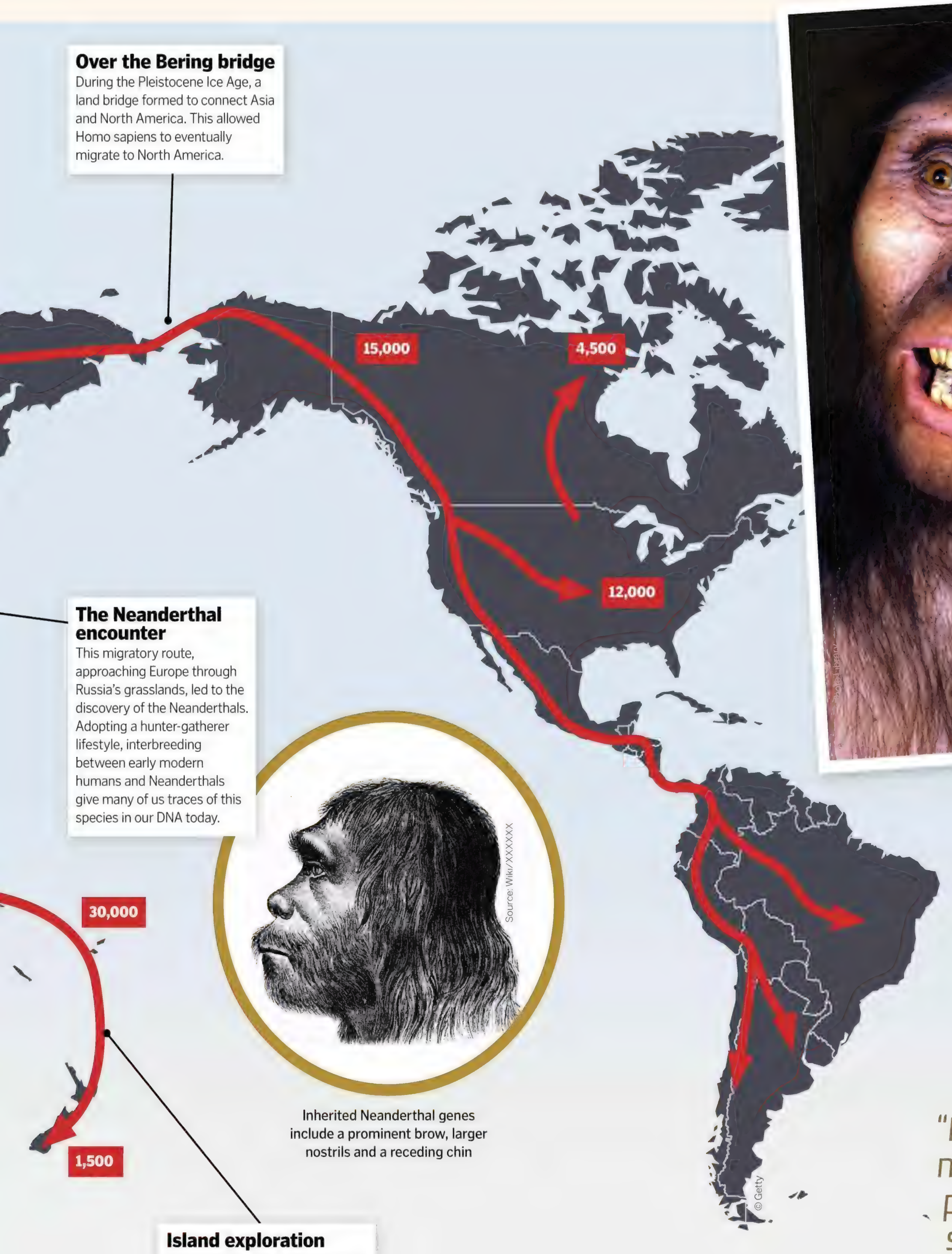
The global spread of humans was gradual

300,000-200,000 years ago
Homo sapiens (modern humans) appeared in Africa.

Around 70,000 years ago
Prior to migration, major climatic shifts may have caused the human population to drop, temporarily nearing extinction.

70,000-100,000 years ago
Modern humans began to leave Africa.

65,000-35,000 years ago
Humans reached the Australian continent, crossing the water in canoes.



Over the Bering bridge
During the Pleistocene Ice Age, a land bridge formed to connect Asia and North America. This allowed Homo sapiens to eventually migrate to North America.

The Neanderthal encounter
This migratory route, approaching Europe through Russia's grasslands, led to the discovery of the Neanderthals. Adopting a hunter-gatherer lifestyle, interbreeding between early modern humans and Neanderthals give many of us traces of this species in our DNA today.

Inherited Neanderthal genes include a prominent brow, larger nostrils and a receding chin

Island exploration
The people following this migration were some of the first to develop rice agriculture before heading out to sea to areas such as Indonesia.

Lucy became the world's most famous early human ancestor

> "Different migration patterns saw the species split"

50,000 years ago
A group leaves the tropical areas of South Asia to explore inland.

20,000 years ago
Moving towards North Asia, groups tackled vast ice sheets on their route from East Asia to North America.

15,000 years ago
After crossing into North America, by 15,000 years ago humans had covered the entire land mass south of this icy region.

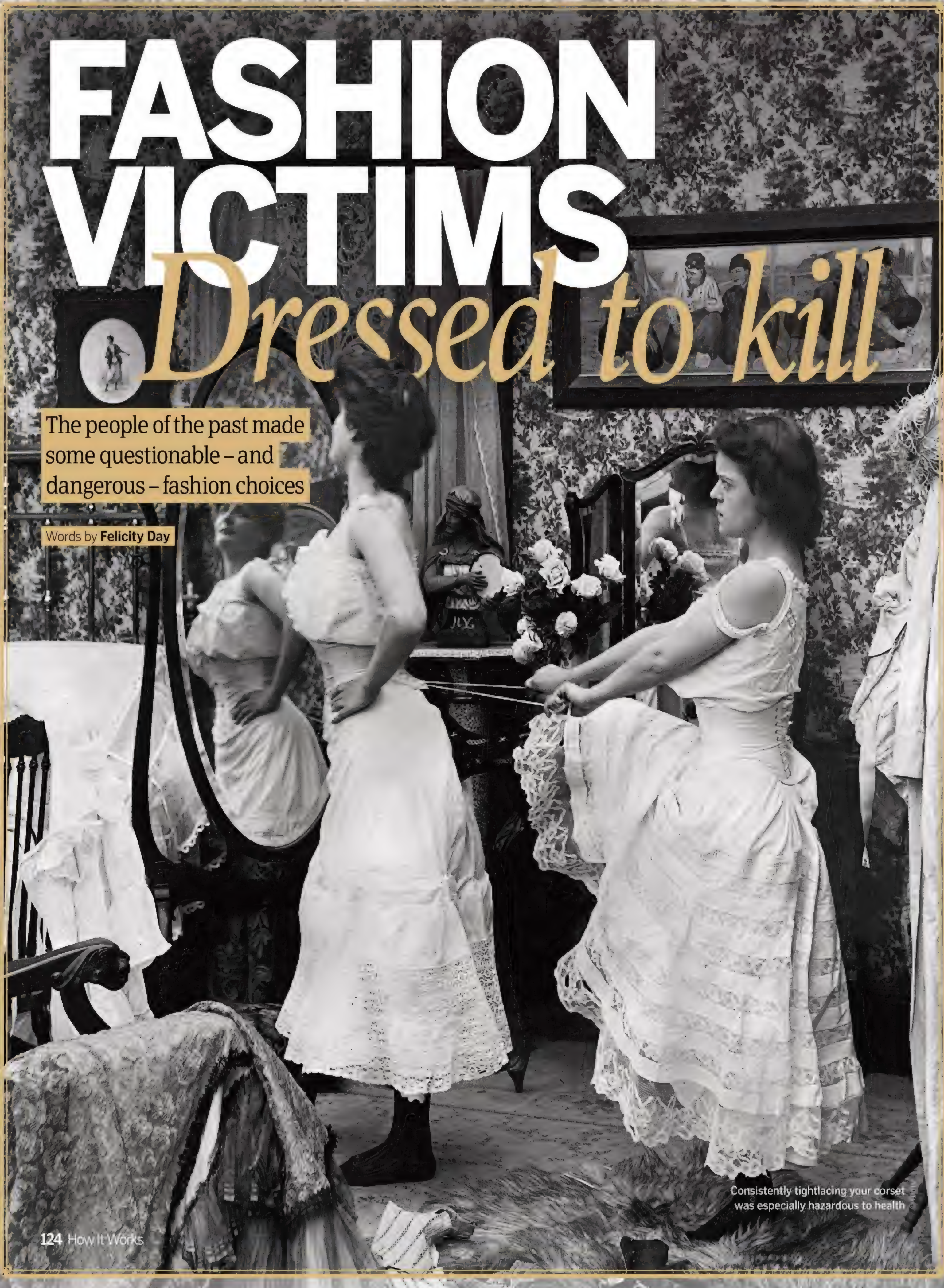
14,000 years ago
Within one thousand years of inhabiting North America, humans had migrated to the very tip of South America.

FASHION VICTIMS

Dressed to kill

The people of the past made some questionable – and dangerous – fashion choices

Words by **Felicity Day**



Consistently tightlacing your corset was especially hazardous to health

Today 'dressed to kill' has a rather different meaning, but in centuries past what you chose to wear could very easily determine how you died. From gowns coloured with poisonous pigments to tight shirt collars that choked them, the clothing our ancestors put on made fashion victims of them, quite literally. Take the corset, for example. Victorian women from socialites to shop girls used the cinching undergarment to achieve the tiny waist that was then the feminine ideal – despite the fact that it inhibited their movement and came with numerous health hazards. While these could be as mild as chronic indigestion, the use of corsets did carry a very real risk of death: if a steel stay snapped, it could easily puncture a woman's internal organs.

Of course, the necessity of using open fires and candle flames for heating and lighting was behind a significant number of the clothing-related deaths of times past. But though our domestic environments have fewer fire hazards today, contemporary fashion trends do still have their perils: the crazes for platform shoes in the 1970s and 1990s, for example, were blamed for rising car accidents, as the super-sized soles were found to slow braking speeds and therefore increase car stopping distances. A 2011 US study also found that there's toxic lead content in some of our most popular brands of lipstick. So beware: deadly fashion is not yet consigned to the history books.

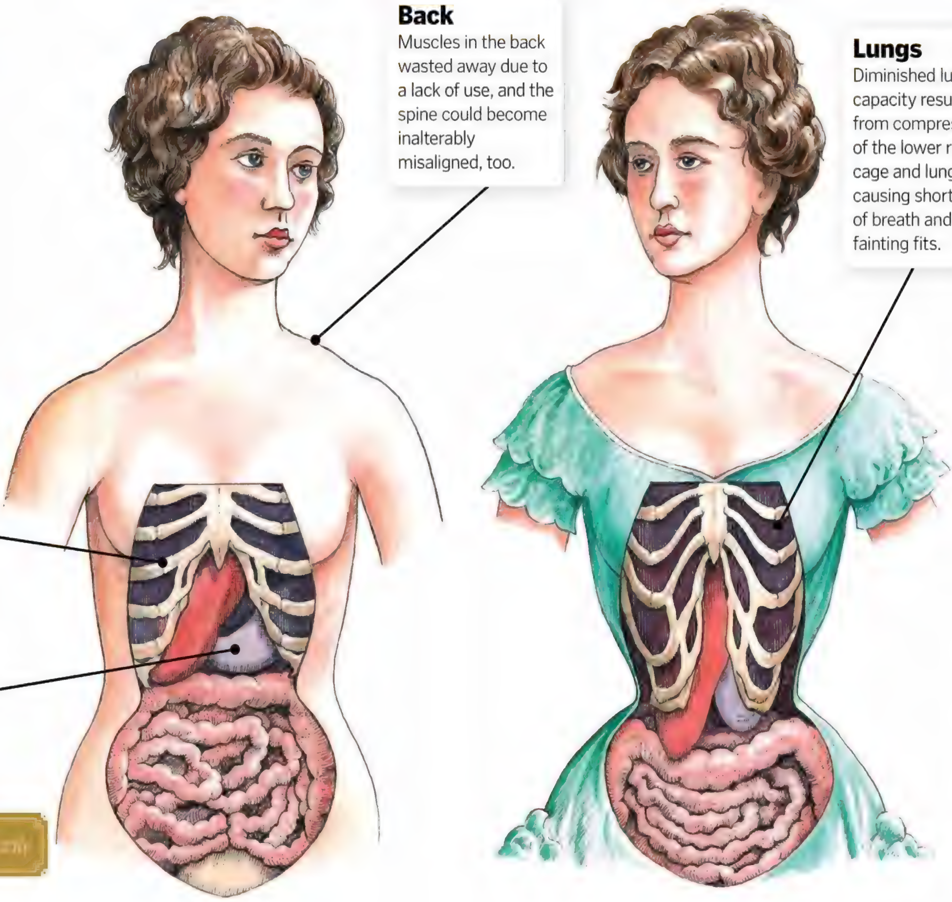
Big wigs

The mid-18th century vogue was for extremes: big dresses and even bigger hair. Towering wigs were hot and heavy to wear, causing sores on the scalp, and they were easily set alight, especially as the hair powder used for whitening and lard for styling made them highly flammable. And there were other reported dangers: long wire pins holding up a lady's lofty coiffure acted like a lightning conductor during a storm in 1778, setting it ablaze and singeing her face. Infestations of lice (or worse, mice) were a persistent problem, since the elaborate hairpieces usually went unwashed for weeks.

Mocked by the press, towering wigs were highly flammable and attractive to vermin

Constricting corsets

Though it successfully cinched the waist, a corset put untold pressure on a woman's body



DANGER RATING Safe ●●●●○ Deadly

Explosive hair combs

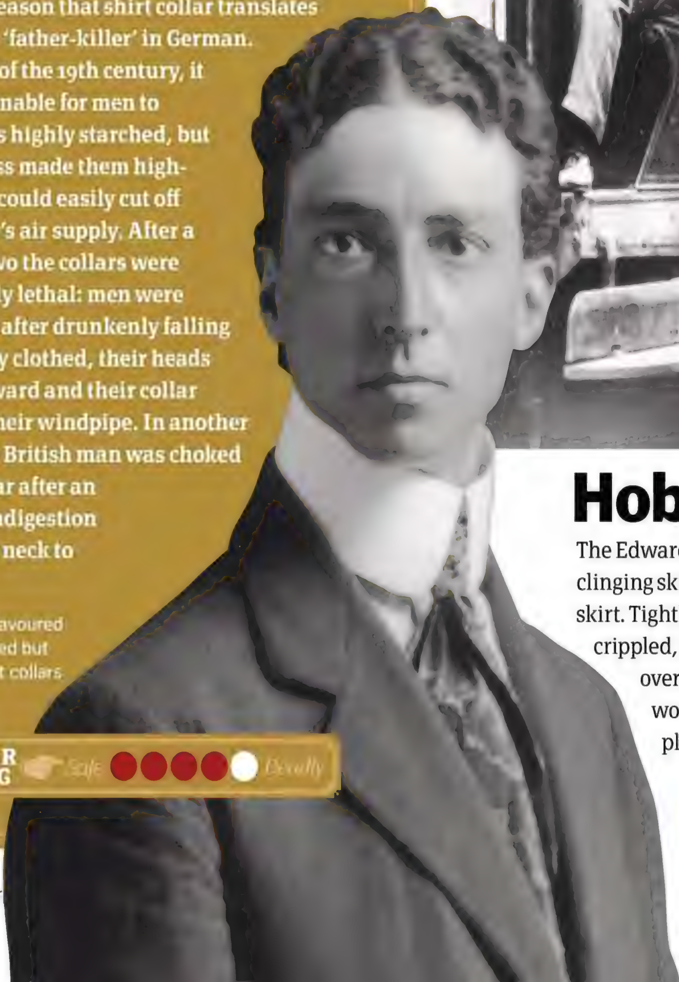
An early form of plastic, celluloid, began to be used to make decorative hair combs in the late 19th century as a cheaper and more animal-friendly alternative to the traditional ivory. But its chemical composition – particularly in cheaper varieties – made it acutely sensitive to heat, so simply sitting near to the fire or using curling tongs could cause a comb to self-ignite – and even explode! They gave women scalp burns and patches of permanent hair loss, and when placed in shop windows in the glare of the Sun, they sent retailers' window displays up in flames after combusting.

Celluloid was used as an ivory substitute in all manner of accessories

DANGER RATING Safe ●●●●○ Deadly

Choking collars

There's a reason that shirt collar translates literally as 'father-killer' in German. At the end of the 19th century, it was fashionable for men to wear theirs highly starched, but the stiffness made them high-risk. They could easily cut off the wearer's air supply. After a tipple or two the collars were particularly lethal: men were suffocated after drunkenly falling asleep fully clothed, their heads tilting forward and their collar stopping their windpipe. In another incident, a British man was choked by his collar after an attack of indigestion caused his neck to swell up.



Stylish men favoured highly starched but high-risk shirt collars

DANGER RATING Safe ●●●●○ Deadly

Toxic make-up

Today we favour a healthy sun tan, but until the late 18th century a pale complexion was highly prized – it was a sign that you were too wealthy to be labouring outdoors. Lead-based make-up, mixed up with vinegar or manure, gave skin the desirable porcelain-white tint, but it corroded it too, causing facial sores. It also dried skin out, causing wrinkles. More worryingly, it slowly poisoned the wearer, who would suffer hair and tooth loss, headaches, muscle paralysis and mood swings before the exposure killed them. Some suspect blood poisoning caused by toxic face paint led to Elizabeth I's death – she had used it religiously to conceal her smallpox scars.

The Earl of Coventry hated his wife's addiction to toxic cosmetics, which allegedly killed her in 1760

DANGER RATING Safe ●●●●● Deadly

A woman models the highly fashionable hobble skirt, which significantly impeded mobility

Hobble skirts

The Edwardian era saw women favouring increasingly narrow and clinging skirts, but the trend took a treacherous turn with the hobble skirt. Tightly cinched in at the knees and ankles, wearers were essentially crippled, able to take only tiny, tottering steps. They frequently toppled over, hitting their heads on pavements, breaking their legs and worse. In 1911 a woman drowned after a stumble caused her to plunge over a low railing into a canal below.

DANGER RATING Safe ●●●○○ Deadly

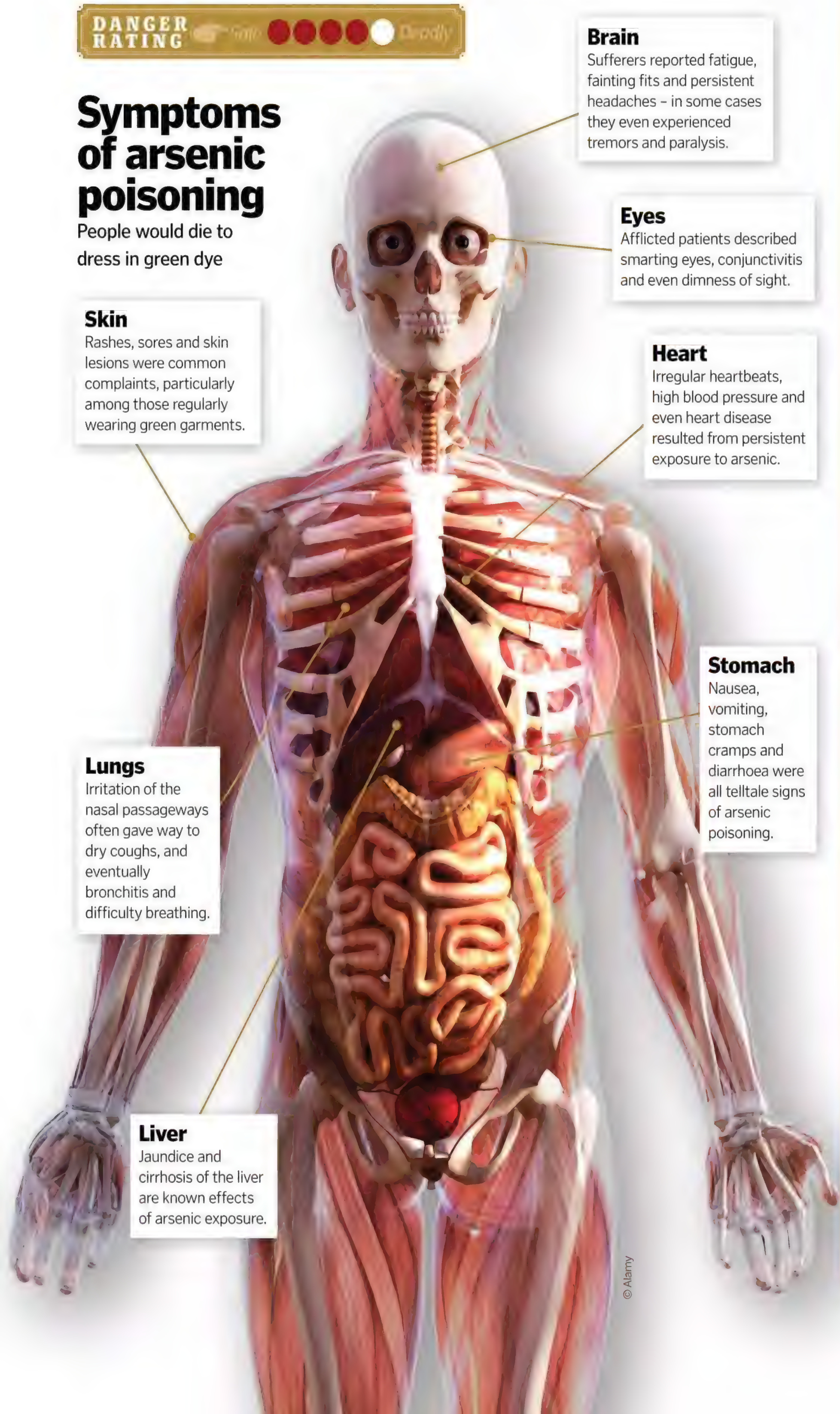
Poisonous pigments

Green dye had been notoriously difficult to create, so when Carl Scheele's chemically produced pigment hit the market in the 1770s it was an instant success. Scheele's Green, along with the similar Emerald Green, became the most fashionable hue for dresses, gloves, hats and headdresses. But thanks to the use of arsenic in its production, green-tinted garments were incredibly toxic: just one gown could contain around 900 grains of the poison, shedding around 60 every time a woman waltzed her way through a single evening party. A lethal dose was just four or five grains! Similarly, a headdress of artificial foliage of the kind favoured by Queen Victoria contained enough arsenic to poison 20 people. Women who went wild for green weren't just endangering themselves, but everyone around them too.

DANGER RATING Safe ●●●●○ Deadly

Symptoms of arsenic poisoning

People would die to dress in green dye



Combustible crinolines

Underneath the voluminous dresses beloved by Victorian women was a crinoline, a circular steel cage that gave the gown its structured shape. But it was deadly. It made their highly flammable muslin and silk skirts unwieldy in size and far more likely to brush against candle flames or fireplaces. And if the skirt ignited, the crinoline acted like a chimney, dramatically increasing the speed with which the fire spread. The huge hoops caused women to blow over cliffs and piers in gusty winds too, and trapped them in industrial machinery and carriage wheels.

DANGER RATING Safe ●●●●● Deadly

The cage crinoline replaced bulky layers of petticoats under women's dresses

Ladies' magazines advised keeping a 'fire cloak' in the house to extinguish an accidental blaze

NUCLEAR ARMS RACE

How two feuding nations stockpiled nuclear weapons in a race to become the dominant military power on Earth

Words by **Scott Dutfield**

Ever since the atom was split in 1917 by physicist Ernest Rutherford, scientists and military engineers alike have worked to weaponise science, culminating in some of the most devastating attacks in human history.

In 1945, two American atomic bombs, dubbed 'Little Boy' and 'Fat Man', were devastatingly dropped on two Japanese cities, Hiroshima and Nagasaki, marking the end of World War II. Seen as a prominent nuclear force at the time, the US had displayed to the world its military power, and in turn stoked a political fire between itself and the USSR, the country now known as Russia. By 1949 the USSR had developed and detonated its first nuclear bomb, RDS-1, also known as 'First Lightning', and almost like the sound of a starting gun, it signalled the start of a nuclear arms race with the US. Who would be the first to cross the finish line, and what would that finish line mean? Total annihilation, perhaps?

Both nations continued developing and stockpiling nuclear weapons in the following years. However, in 1952 the US pulled ahead with the creation of the hydrogen bomb. Previous atomic bombs, such as those used on Hiroshima, utilised the explosive energy produced in nuclear fission. Uranium and plutonium were used in this process to create a chain reaction of splitting atoms. A hydrogen bomb uses nuclear fusion with the addition of tritium and a hydrogen isotope called deuterium. In this reaction atoms are forced together, releasing explosive energy around 1,000 times more powerful than the WWII bombs.

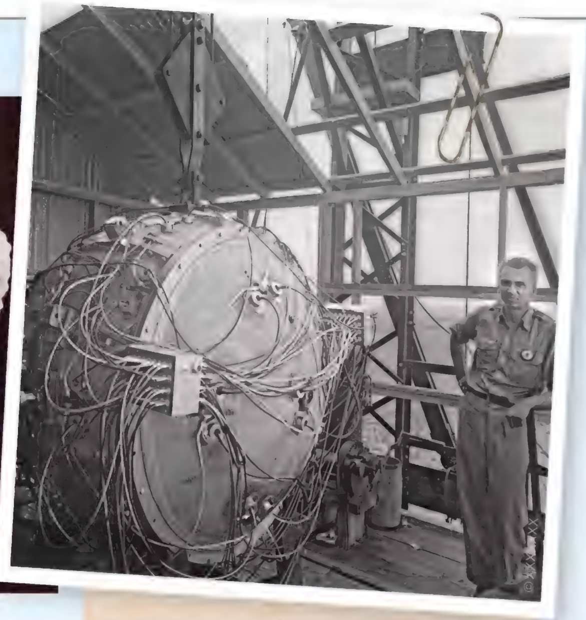
After the US had detonated its hydrogen bomb in Eniwetok Atoll, a chain of islands in the Pacific, it only took the USSR a year to test its own hydrogen creation, presenting the very real threat of globally destructive nuclear warfare. As political tension grew between the two nations during the Cold War, the conflict reached a boiling point in what is now known as the Cuban Missile Crisis of 1962.

In a 13-day standoff between the US and the USSR, the world held its breath after the US discovered that the USSR had been building and storing nuclear weapons in Cuba, just 145 kilometres from Florida. Creating a blockade around the island, the US prevented military supplies from entering the country in hopes of starving USSR nuclear supplies to Cuba. This act of quarantining Cuba was seen as an act of aggression by the USSR, and diplomatic resolution appeared to be unachievable.

However, much to everyone's surprise a resolution was found after America threatened to invade Cuba, and the USSR retreated from the island. It later came to light that the USSR's retreat came with a condition: that the US would remove its nuclear arsenal from Turkey. The two nations constructed a doctrine called mutual assured destruction, in which both nations recognised that if one launched missiles against the other, the retaliation would lead to both countries suffering terrible nuclear fallout.

By July 1968 the Treaty on the Non-Proliferation of Nuclear Weapons was signed by the US, the Soviets and the British. The treaty sought to prevent any country without nuclear weapons at the time from developing them. In the years that followed, several nuclear treaties between the US and the Soviet Union were signed, such as the Strategic Arms Limitation Talks (SALT I) and SALT II, to ease tensions between them and limit production of nuclear weapons.

The Americans' first full-scale hydrogen bomb was detonated in 1952



The 'Gadget' was a plutonium device, similar in design to the Fat Man bomb that was later dropped on Nagasaki, Japan

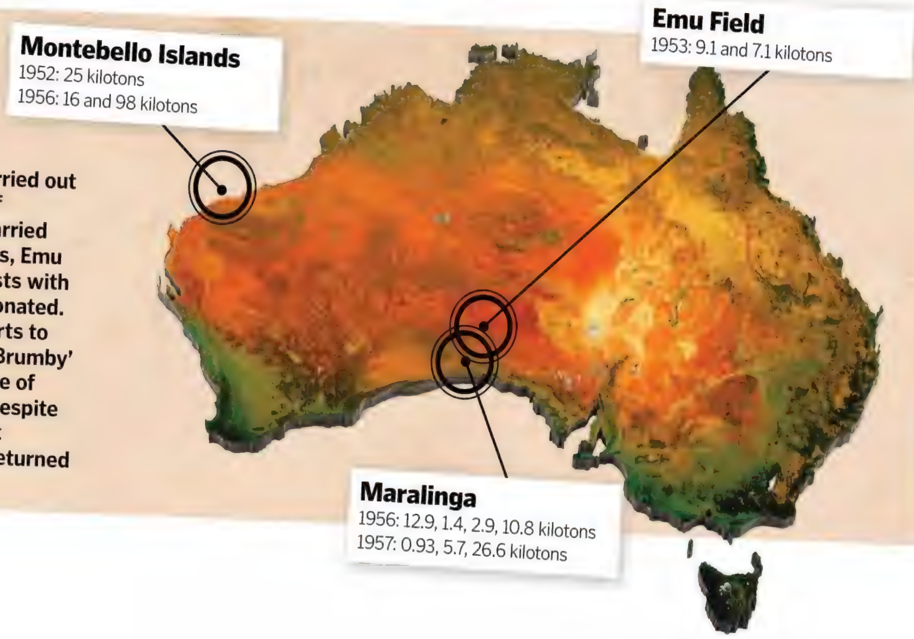
Autunite can be used as an ore of uranium

BUILDING THE A-BOMB

The Manhattan Project changed the course of history forever, ultimately leading to the death of hundreds of thousands of people. After the discovery of nuclear fission by German scientists Otto Hahn and Fritz Strassmann in 1938, fears grew in the US that Nazi Germany may be able to develop the first atomic bomb. To beat the Germans to the punch, President Franklin Delano Roosevelt assembled a team of scientists and military experts, known as the Uranium Committee, to evaluate the use of nuclear fission and become the first nation to weaponise the newfound science. Having deduced its potential for the creation of a new type of bomb, the Manhattan Project was formed in 1942, named after the location of the office headquarters. Three years later the project bore its first explosive fruit, the 'Gadget' plutonium bomb, an invention that led to the nuclear arms race.

THE UK BOMBS AUSTRALIA

Between 1952 and 1963 the United Kingdom carried out a series of nuclear tests on the arid continent of Australia, with the government's permission. Carried out over three locations – the Montebello Islands, Emu Field and Maralinga – 12 major nuclear bomb tests with a yield ranging from 1.4 to 98 kilotons were detonated. In the years that followed, the British made efforts to clean up their nuclear mess. In 1967 'Operation Brumby' removed and buried waste and debris in the hope of diluting the UK's radioactive residue. However, despite its best efforts, 60 years on the land has still not completely recovered, and wildlife has still not returned to these contaminated areas.



TRAJECTORY TO A NUCLEAR WORLD

1945 United States
The world's first successful detonation of a nuclear bomb occurred in July 1945 at the Trinity test site, Jornada del Muerto desert, New Mexico.

1949 Soviet Union
In August 1949, the Soviet Union tested its first nuclear bomb, RDS-1, at the Semipalatinsk Test Site in what is now modern-day Kazakhstan.

1952 United Kingdom
Tested on islands off mainland Australia, the UK dropped its first bomb back in October 1952 after creating a nuclear programme in 1947.

1960 France
Entering the nuclear race in February 1960, France detonated its first bomb in the Sahara Desert of Algeria, called 'Gerboise Bleue', or Blue Jerboa, with an explosive yield of 70 kilotons.

1964 China
Following assistance from the Soivet Union until the late 1950s, in October 1964 China detonated its first nuclear bomb, code-named Project 596, releasing 22 kilotons of explosive power.

Mid-1950s to 1960s
Israel
Although a nuclear test has never been conducted by Israel, it's widely believed that the country has nuclear capabilities.

1974 India
Beginning its nuclear programme in 1944, it wasn't until May 1974 that India showcased its military efforts with a eight-kiloton bomb, code-named 'Smiling Buddha'.

1998 Pakistan
As a retaliation to a series of nuclear tests conducted by India in 1998, Pakistan conducted its first nuclear tests, six to be exact, in May of the same year.

2006-2017 North Korea
Despite threats from the US against testing nuclear weapons, North Korea conducted six underground nuclear tests beneath the mountainous site called Punggye-ri since October 2006.

The scale of nuclear test explosions is enormous

"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION

NEW YORK, MONDAY, OCTOBER 29, 1962. FIVE CENTS

U.S. AND SOVIET REACH ACCORD ON CUBA; KENNEDY ACCEPTS KHRUSHCHEV PLEDGE TO REMOVE MISSILES UNDER U.N. WATCH

DE GAULLE WINS 61% OF BALLOTS; ABSTENTIONS HIGH

THANT SETS VISIT

He Will Go to Havana Tomorrow to Seek Castro Consent

RUSSIAN ACCEDES

Tells President Work on Bases Is Halted —Invites Talks

CAPITAL HOPEFUL

Plans to End Blockade as Soon as Moscow Lives Up to Vow

Castro Asks Guantanamo; Strives to Repair Prestige

Plane Veers Over Soviet, Kennedy Voices Regrets

WARFARE ALTERS

PATROLS MAINTAIN

The Cuban Missile Crisis was the closest humankind has ever come to nuclear warfare

'Fat Man' was the second of only two nuclear weapons ever to be used in war

Vasili Arkhipov's reluctance to launch a nuclear torpedo may have saved life as we know it

THE MAN WHO SAVED THE WORLD

During the Cuban Missile Crisis, a decision made by a single Soviet Navy officer potentially saved the entire world. After US President John F. Kennedy initiated a blockade on shipments to Cuba, a Soviet submarine was travelling towards the shores of the US, carrying a nuclear torpedo. As the submarine approached the blockade, several explosive charges were dropped into the surrounding waters by American ships in an attempt to ward away the submarine and force it to surface. However, with the threat of nuclear warfare looming, it's believed that captains aboard the vessel saw this as an indication that the war had already begun. Soviet protocol demanded that three high-ranking personnel must be in agreement to launch the nuclear weapon. Two of the submarine's officers had their detonation keys ready and waiting. However, the third, Vasili Alexandrovich Arkhipov, refused. It's reported that Arkhipov recognised the charges for what they were, and not as the instigation of World War III. Without all three officers in agreement, the launch was aborted and nuclear war was averted.

AR ZONE!

DEADLY DEFENCES

The UK's nuclear submarines patrol the country's coastline, armed and ready with nuclear warheads

The US tested nuclear weapons at Bikini Atoll during the 1940s and 1950s

Following direction
Aboard the Trident missile is a MK 6 stellar-inertial navigation system capable of delivering the warhead to within around 120 metres of its target.

Powerhouse
Held within the head of each missile are multiple independently targetable re-entry vehicles (MIRVs) – six 100 kiloton thermonuclear warheads.

Launch
Pressure from expanding gas within the storage tubes behind the submarine's fin builds until it's enough to launch the Trident missile.

UGM-133A Trident II D5
Length: **13 metres**
Weight: **58,500 kilograms**
Range: **12,000 kilometres**
Cost: **£41.3 million per missile**

AR ZONE! SCAN HERE

Flight
Once it escapes the water's surface and it's far enough away from the submarine that deployed it, the airborne missile uses a three-stage solid-propellant rocket to soar through the skies.

Floating storage
16 Trident missiles can be stored on each of the UK's four Vanguard-class submarines.

MODERN-DAY THREAT

Russia and the US have around ten times the number of warheads the rest of the world has combined

RUSSIA 6,490

THE US 5,800

FRANCE 300

CHINA 290

THE UK 215

PAKISTAN 150

INDIA 130

ISRAEL 80

NORTH KOREA 20

In 1945, the first-ever nuclear device was detonated in the New Mexico desert

NUCLEAR WEAPONS by numbers

Fat Man and Little Boy killed over

200,000 PEOPLE

between the attacks on Hiroshima and Nagasaki, Japan

At today's consumption rate, there is around

230 YEARS

worth of uranium available from known sites on Earth

A nuclear explosion can reach temperatures of around

100 MILLION DEGREES CELSIUS

1,814 TONNES

The average uranium-mining waste created by manufacturing a single nuclear bomb

BETWEEN 1945 AND 2017 THERE HAVE BEEN

2,056

nuclear weapons tests around the world

50 MEGATONS

The most powerful known nuclear bomb wss the Russian RDS-202 Tsar Bomba, tested in 1961

An average nuclear weapon test would destroy everything within a

80 KM RADIUS

Hieroglyphs

Understanding the language of the gods

In order to learn the Egyptian script – known in ancient times as medu neter or 'words of god' – it is best to start with the alphabet, which is published here in full. As you start to recognise the words and names in the Egyptian script you begin to understand the excitement and adrenaline that historians must feel when deciphering an ancient text – by doing so you gain a unique insight into this incredible and mysterious civilisation.

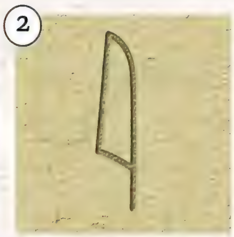
The language is elaborate but also very accessible. It employs a series of grammatical structures that include verbs, nouns, negatives and particles; the Egyptians also used onomatopoeic words – for example 'cat' is written 'meow'. The language also contains a series of pictograms and phonograms, and is interspersed by determinatives. These are placed at the end of words in order to clarify their meaning.

The script has an abundance of symbols that reflect the natural world. Birds, mammals and trees often provide clues to the true meaning of the text. The language could be written left to right or right to left, and executed vertically or horizontally. The script is continuous and you can learn to separate the words by identifying the determinative or the strokes at the ends of each section.

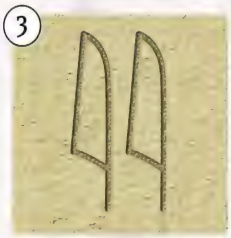
"The language could be written left to right or right to left, and executed both vertically or horizontally"

1

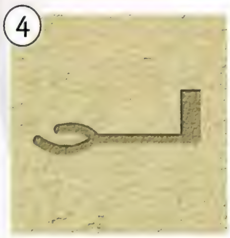

ꜣ ('ahhh')
Egyptian vulture. This ominous bird is associated with both battlefields and graveyards.

2


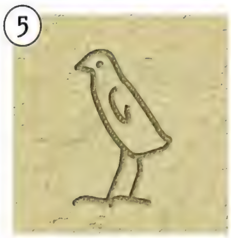
i
A flowering reed. The reed was used to make arrows and writing tools.

3


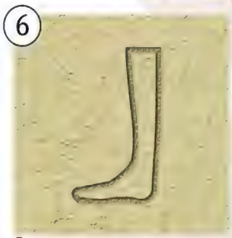
y ('eee')
Two flowering reeds or strokes that may have represented the sound of the wind on rushes.

4


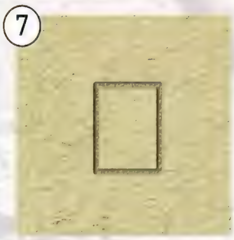
ᶜ (e)
The arm is often used in the Egyptian language to represent might or power.

5


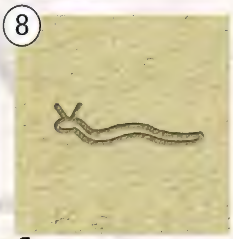
w ('ooo')
The quail chick adds a pleasant sound. It is often employed among signs that represent time.

6


b
The foot and leg. Egyptians became familiar with human anatomy through mummification.

7


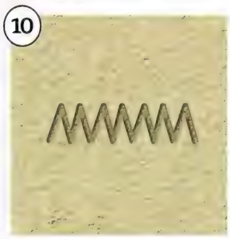
p
A seat, stool or throne. A sign in ancient Egyptian used frequently in royal titles.

8


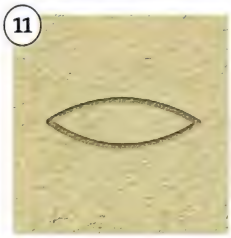
f
The horned viper is one of many snakes used in ancient Egyptian; it is often attached to a verb.

9

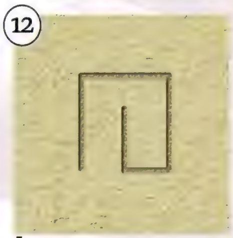

m
The owl is a common letter. It is rare to see the full face of any creature in imagery.

10


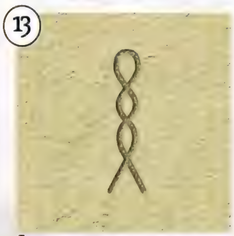
n
A water ripple is used to note transience; the words 'to' and 'towards' often contain this.

11


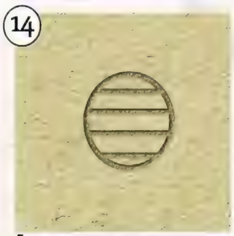
r
R is shown as a mouth. The letter is used in the words 'recitation', 'to eat' or 'to speak'.

12


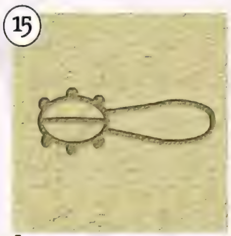
h
There are various 'h' sounds in the alphabet. This sign shows a rural shelter or a house.

13


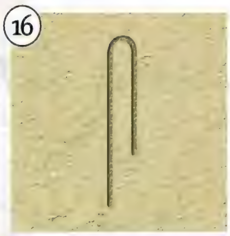
h (emphatic 'h')
A twisted piece of flax. Flax was a common material in ancient Egypt.

14


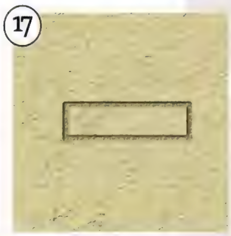
h (as in hock or lock)
The placenta can be found in many words, including those that deal with fortune and smell.

15


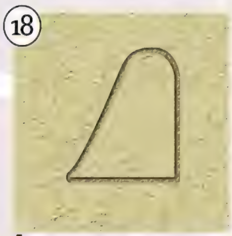
h ('ich')
The belly of an animal; this letter is used in words that denote the physical form.

16


s
A door bolt and a folded sheet of cloth. It sounds like the English 's'. It has several different variations.

17


s ('sh')
Water features were a symbol of affluence, and upper-class villas were designed with pools.

18


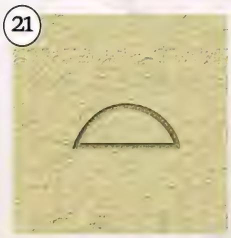
k (like 'qu' in quaint)
The hill sign is used in the words 'tall', 'high' and 'exalted', as well as 'high ground' or 'summit'.

19

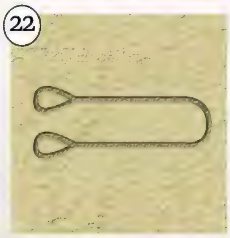

k
A reed basket with a handle. This can be used in many contexts and is employed as the pronoun 'you'.

20


g
The Egyptians were fond of wine. The sign of this jar stand is transliterated with a hard 'g'.

21


t
Bread was the most basic food in Egypt; here we see a small loaf of oven-baked bread.

22


t ('tsh')
Tethering rope. The Egyptians had 38 signs for ropes and baskets. 't' is also a pronoun.

23


d
Human hand. There are 63 signs for the human body. This sign was used for words of action.

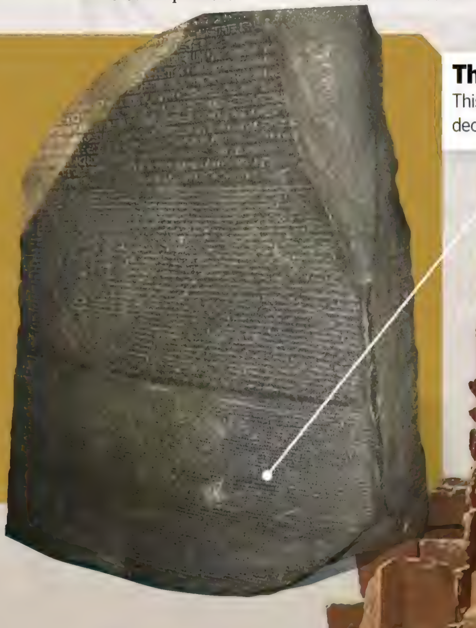
24


d (dj)
Snakes were feared creatures. This letter is often used in words of declaration or recitation.

The Rosetta Stone

The ultimate codebreaker

The Rosetta Stone is viewed as one of the most remarkable finds of the ancient world. It was discovered in Egypt in 1799. The top and middle sections of the stone are carved with hieroglyphs and demotic – a variation of the Egyptian text. The lower section is in Greek script, which ultimately acted as a codebreaker for the upper sections. A series of scholars were involved in the race to decipher the hieroglyphic code, but the breakthrough is credited to Jean-François Champollion. Champollion used the Greek portion of the text to reveal the secret language of the pharaohs.



The missing link
This section helped decipher the hieroglyphs.

AR ZONE!

What are totem poles?

While only specialists are trusted to carve these mighty sculptures, it takes a village to raise them

Totem poles are one of the most iconic examples of Native American art. They're found in the Yukon and British Columbia regions of Canada, as well as Alaska and Washington in the US. Created by the Northwest Coast indigenous peoples, each community has its own methods of designing totem poles. The Haida, for instance, often carve creatures with bold eyes, whereas the Kwakwaka'wakw poles typically have narrow eyes. The Coast Salish carve images of people, while the Tsimshian prefer supernatural beings on their poles.

All of them were made by skilled craftsmen. They would make totem poles out of the trunks of giant red cedars. It could take months, during which time the wealthy families that commissioned the artwork would be responsible for feeding the carver and any assistants they had.

The whole community was invited to take part in a totem pole's raising. It might take hundreds of men to carry it to the site where it would be erected. A deep trench was dug to keep the pole upright, while it was carefully put in place in stages using strong ropes and stakes. And though they weren't religious artefacts, a pole-raising would often be an excuse for a celebration. The carver would dance around the pole to the sound of drums. There might even be a feast and gift-giving.

In the northwest Pacific's mild, wet climate, few poles made before the 20th century still exist. But archaeological evidence suggests they were being carved hundreds of years before the first European explorers arrived.

Totem poles were effectively banned for over 60 years by the Indian Act in Canada in 1876. They were also forbidden under the US Code of Indian Offenses in 1884. But today totem poles are once again celebrated, with some of the tallest ever carved in the 1960s and 1970s.


Totem poles are typically made out of red cedars, which can grow up to 37 metres tall

AR ZONE! SCAN HERE

Types of totem

While Northwest Coast peoples mostly passed down knowledge by word of mouth, when they wanted to preserve important information a totem pole would be made. The details would be told to a carver, who would be able to visualise the right symbols and encode the story into a sculpture. This could range from who owned the rights to what territories to genealogical records.

Memorial poles honoured deceased chiefs and high-ranking members. They would depict a person's accomplishments or family history. Haida mortuary poles also honoured the dead, topped with a box containing the deceased's ashes. Legacy poles commemorated important historical events, while family poles featured animals that made up a clan's crest.

Less common were shame or ridicule poles, which criticised neighbours for being offensive or not paying their debts. Chiefs also used these poles to belittle their rivals.


A Coast Salish totem at Brockton Point in Vancouver, British Columbia

A curse on Virginia Water

In 1958, Canada gifted a totem pole to the queen to mark the centenary of British Columbia. Commissioned in her honour, the sculpture was 30 metres tall and weighed 12 tons. Each of its elaborate carvings representing a different indigenous clan. It was shipped to Britain via the Panama Canal and put on public display at Virginia Water Lake, Surrey. However, its chief sculptor, Mungo Martin, an eminent Kwakwaka'wakw artist, was so offended at not be invited to the pole-raising he put a curse on his creation. By way of apology, Martin and several other Kwakwaka'wakw members were flown over and invited to perform a dedication dance that lifted the curse.

Mungo Martin's totem pole arrives at the entrance of Windsor Great Park

© Getty

The snake

While European art often depicts serpents as evil, the skin-shedding reptile represents change, medicine and fertility in some Native American cultures.

The wolf

While revered as a cunning hunter, wolves live in packs so are also often used to represent loyalty and strong family ties.

The beaver

Capable of building mighty dams, beavers symbolise both creativity and determination, while appearing in many indigenous stories.

A skilled carver at work chiselling a face into a log in 1959

© Getty

"Few poles made before the 20th century still exist"

Painted totem poles, each one carved symbolically to display a message or story

© Getty

The bear

Often featured in family crests, the grizzly bear stands for strength and authority, but also motherhood, teaching and humility.

Putting up a pole

Here's how to go from lowly log to towering totem

Select a tree

The Northwest Coast peoples favour red cedars because they're soft but long-lasting. However, you also need to find a tree that's tall, straight and free of knots, and near a river, so that it can be floated to the carving site.

Chop it down

There are different ways to fell your cedar. The easiest is to light a controlled fire at the base of the trunk. Or you could go round it several times with a chisel, maul and wedge, stripping out sections at a time.

Carve the figures

After stripping the bark, outline the design in charcoal. The most important figure should go at the bottom where people can see them. Carve using traditional tools: bone-pointed drills, stone hammers, wooden chisels, etc.

Paint the pillar

Use a paintbrush made from sea otter hairs and other fibres. Not every group paints their poles, but the two most common colours to use are red and black, traditionally made from salmon blood and charcoal.

© Ed Crooks

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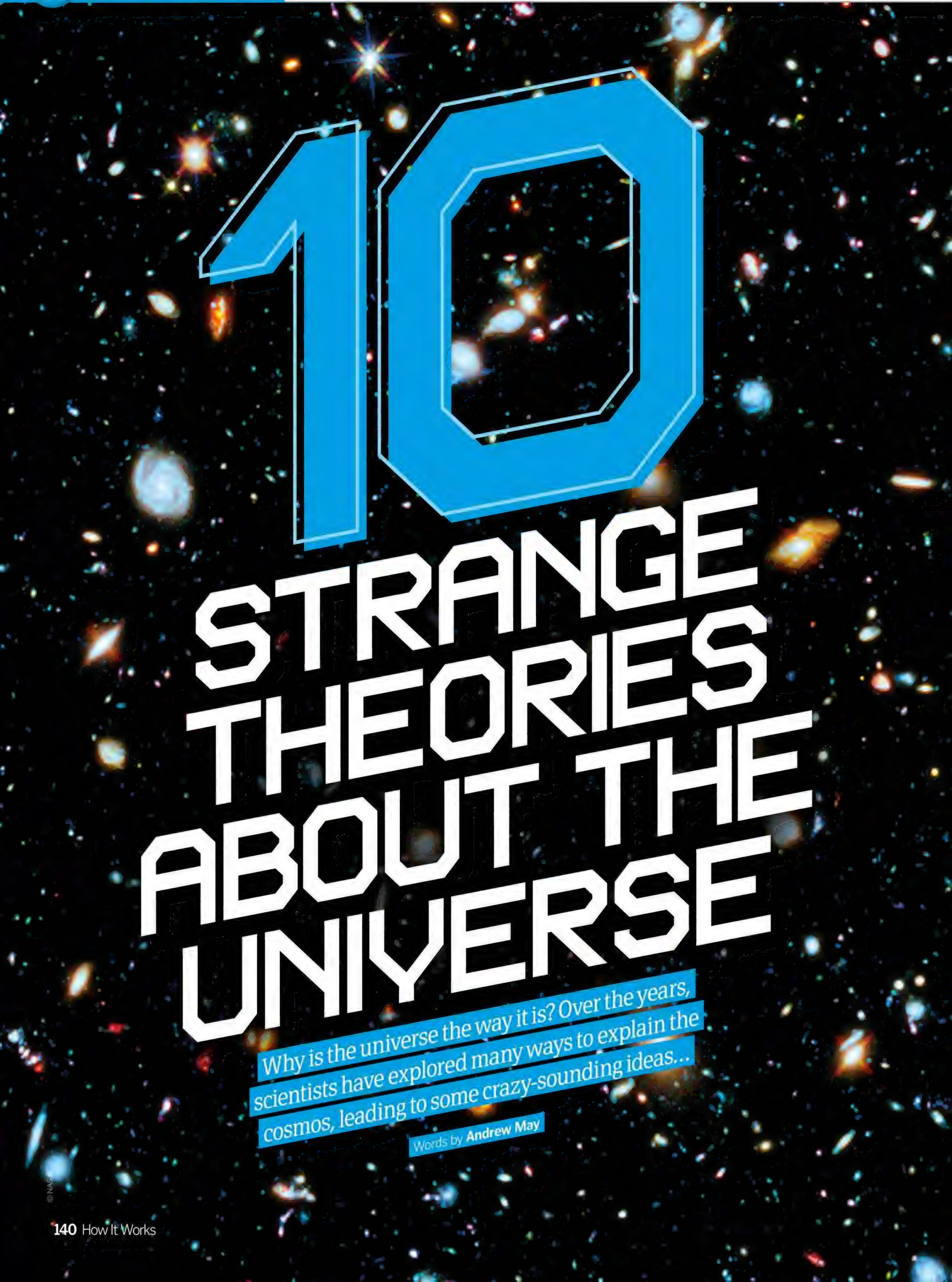


10 STRANGE THEORIES ABOUT THE UNIVERSE

Why is the universe the way it is? Over the years, scientists have explored many ways to explain the cosmos, leading to some crazy-sounding ideas…

Words by **Andrew May**

© NASA

1 Braneworld

An aspect of the universe we take for granted is that it's three dimensional – there are three perpendicular directions you can move in. Some theories, however, suggest another spatial dimension – which we can't perceive directly – in another perpendicular direction. This higher dimensional space is referred to as 'the bulk', while our universe is a three-dimensional membrane – or 'brane' – floating inside the bulk.

As complicated as it sounds, the braneworld picture solves several problems in physics. For example, a version proposed by Lisa Randall and Raman Sundrum explains an asymmetry in subatomic forces by suggesting the existence of other branes parallel to our own. But it's not enough for a theory to explain facts we already know – it has to make new predictions that can be tested experimentally. In the case of the Randall-Sundrum model, such tests could involve measuring gravitational waves emitted by black holes linking our brane to another.

Insane in the brane

Crazy theory or the truth of the cosmos?

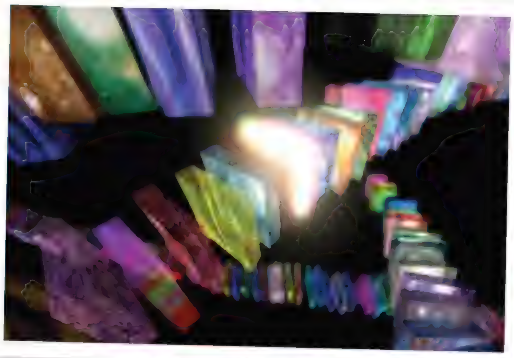
The bulk
It's difficult to show in a two-dimensional image, but this is a four-dimensional space containing our own three-dimensional brane, and others.

Parallel brane
There may be many other branes in the bulk, some only a short distance away in the fourth spatial direction.

Smaller black hole
The pattern of gravitational waves produced by the orbiting black hole will be different if the braneworld theory is correct.

Black string
A large black hole might actually be a 'black string' spanning the gap between our brane and a nearby one.

Our brane
Our three-dimensional universe is embedded in the bulk, analogous to a two-dimensional membrane in a three-dimensional space.

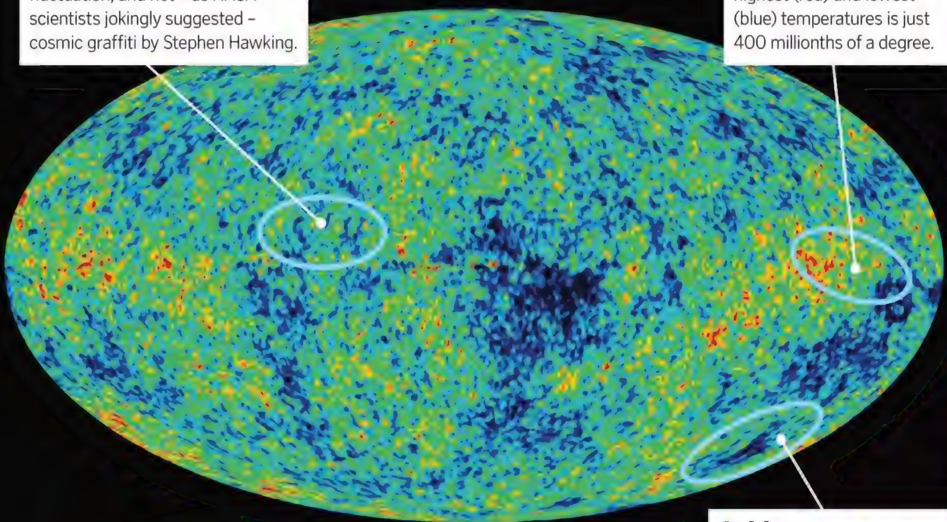


© NASA

Artist's impression of multiple 'braneworlds'. When two collide, they may create a new universe

2 The Big Splat

In the far future, galaxies will eventually drift so far apart that light from one can never reach another. In fact, as stars get old and die, there will come a time when there's no light – or heat – left. The universe will be a dark, cold, empty void. It sounds like the end of everything, but according to one theory, it's actually the beginning of the next universe in an endlessly repeating cycle. Remember the braneworld theory? What happens when one cold, empty brane collides with another – which, given enough time, it's bound to do eventually. Cosmologists Neil Turok and Paul Steinhardt believe such a collision would generate enough energy to create a whole new universe. They call this the 'ekpyrotic theory', though physicist Michio Kaku has more evocatively dubbed it the 'Big Splat'.



3 Plasma-filled cosmos

The Big Bang remains the preferred theory of many scientists, supported by two key observations – the expansion of the universe and the cosmic microwave background (CMB). Immediately after the Big Bang the universe was much smaller and hotter, filled with a glowing plasma like the Sun. We still see the end of this super-hot phase in the form of a sea of radiation filling the whole of space. The expansion of the universe over the intervening billions of years has cooled the radiation down to minus 270 Celsius, but it's still detectable by radio telescopes.

The CMB looks virtually the same in every direction, which can't be explained if the universe has always expanded at its current rate. Many scientists believe it went through a brief period of extremely rapid 'inflation' a fraction of a second after the Big Bang, suddenly ballooning in size from a subatomic scale to several light years.

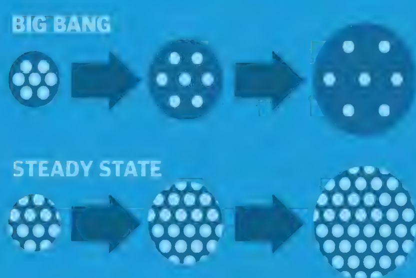
The holographic universe

4 Think of a security hologram. This is basically a two-dimensional object encoding a full three-dimensional image. According to this theory, the whole three-dimensional universe may be 'encoded' on its two-dimensional boundary. It may not sound as exciting as living inside a simulation, but it has the advantage that it's a scientifically testable theory – research in 2017 showed it was consistent with the observed pattern of CMB fluctuations.

The universe, like this hologram, may have just two dimensions despite appearing to have three

The steady-state universe

5 The Big Bang is an evolutionary theory in which the universe changes in appearance as it expands. It was denser in the past, and it will become less dense in the future. Not all scientists were happy with that, so they came up with a way for the density to remain constant, even in an expanding universe. It involves the continuous creation of matter at the rate of about three hydrogen atoms per cubic metre per million years. This model fell out of favour with the discovery of the CMB, which it can't easily explain.



To keep the density of the universe constant, new matter must be created continuously

6 The multiverse

In the conventional view of the Big Bang, in order to explain the uniformity of the CMB, it's necessary to postulate an early spurt of superfast expansion known as inflation. Some scientists believe that when our universe dropped out of this inflationary phase, it was just one tiny bubble in a vast sea of inflating space. In this theory, called 'eternal inflation', other bubble universes are constantly popping up in other parts of the inflationary sea, with the whole ensemble making up a 'multiverse'.

The theory gets even stranger, because there's no reason other universes should have the same laws of physics as ours – some might have stronger gravity, or a different speed of light. Although we can't observe the other universes directly, it's conceivable one of them could collide with our own. It's even been suggested the 'cold spot' in the CMB is the imprint of such a collision.

Is our universe just one bubble in a vast multiverse?

7 We got gravity wrong

Theories of the universe depend on an accurate understanding of gravity – the only force in physics that affects matter on very large scales. But gravity alone can't explain certain astronomical observations. If we measure the speed of stars on the outskirts of a galaxy, they're moving too fast to remain in orbit if the only thing holding them is the gravitational pull of the visible galaxy. Similarly, clusters of galaxies appear to be held together by a stronger force than can be accounted for by the gravity of visible matter.

There are two possible solutions. The standard one – favoured by most scientists – is that the universe contains unseen 'dark matter' which provides the missing gravity. The maverick alternative is that our theory of gravity is wrong, and should be replaced by something called Modified Newtonian Dynamics (MOND). The two options – MOND and dark matter – are equally consistent with observations, but are yet to be proven. More experiments are needed.

Is our galaxy surrounded by dark matter, or is the theory of gravity wrong?

> "Gravity can't explain certain astronomical observations"

5 FACTS ABOUT THE BIG BANG

1 An accidental discovery
The CMB was a key prediction of the Big Bang theory, so many people looked for it. It was eventually found in 1964 by radio astronomers looking for something else.

2 Space itself is expanding
Although we say the universe is expanding, it's really the fabric of space itself. Any two galaxies that aren't tied to each other by gravity are getting further apart.

3 Faster than light
Physical objects can't travel faster than light, but that doesn't apply to the stretching of space. During the universe's inflationary phase, space expanded much faster than light.

4 The start of everything
Stephen Hawking believed that both space and time were created at the Big Bang. Before that, neither time nor space existed.

5 The missing link
The reason why there are so many competing theories of the universe is that physicists don't know how to combine gravity and quantum physics. Until they do, it's all guesswork.

According to some philosophers, the universe is a computer-generated illusion projected into our brains

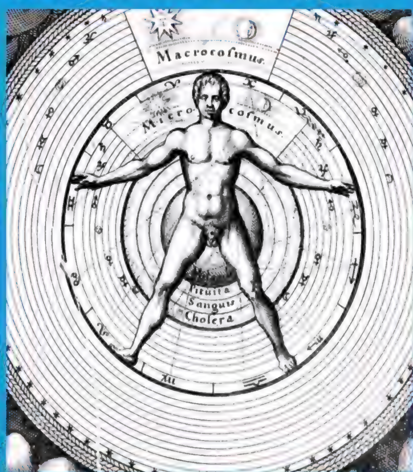
© Getty

Simulation theory

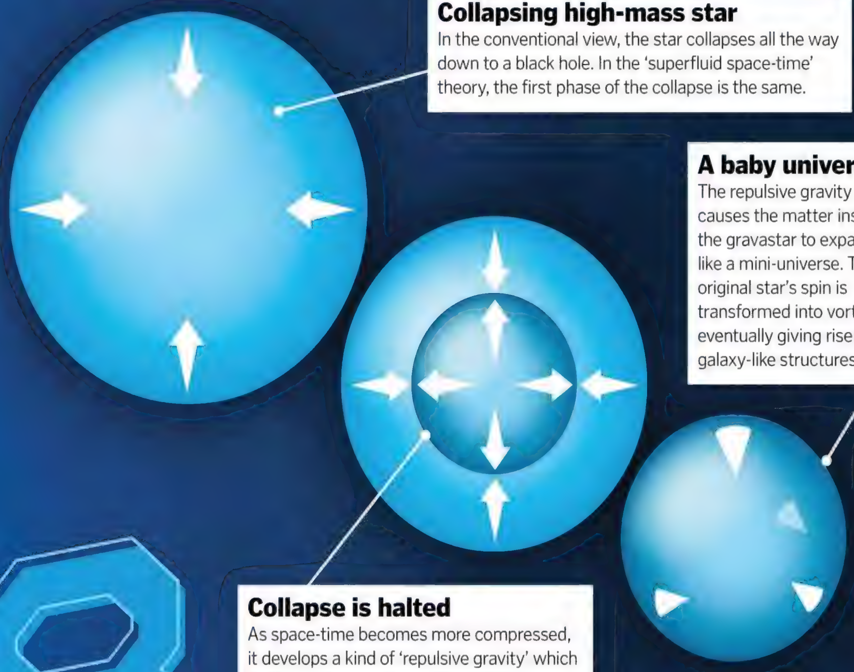
9 So far, all the theories have come from scientists – but here's one from the philosophers. If all our evidence about the universe comes into our brains via our senses and scientific instruments, who's to say it isn't all a cleverly designed illusion? The entire universe might be nothing but an ultra-sophisticated computer simulation. It's an idea that was popularised by the *Matrix* movies, but as outlandish as it sounds it's taken seriously by some philosophers. However, it fails the test of a true scientific theory, because there's no way it could be proved true or false.

Cosmic ego-trip

10 The laws of physics involve a handful of fundamental constants that determine the strength of gravity, electromagnetism and subatomic forces. As far as we know, these numbers could have any possible value – but if they departed even slightly from the values they actually have, the universe would be a very different place. Most importantly for us, 'life as we know it' – including, of course, ourselves – couldn't possibly exist. Some people see this as evidence that the universe was consciously designed in order for human-like life to evolve – the so-called self-centered 'anthropic theory'.



The anthropic theory revives the notion that the universe was designed around human beings



Collapsing high-mass star
In the conventional view, the star collapses all the way down to a black hole. In the 'superfluid space-time' theory, the first phase of the collapse is the same.

A baby universe
The repulsive gravity causes the matter inside the gravastar to expand, like a mini-universe. The original star's spin is transformed into vortices, eventually giving rise to galaxy-like structures.

Collapse is halted
As space-time becomes more compressed, it develops a kind of 'repulsive gravity' which pushes outwards, preventing further collapse. Rather than a black hole, the star becomes what's called a 'gravastar'.

8 Superfluid space-time

Even if space only has three dimensions, there's still a fourth dimension in the form of time, so we can visualise the universe existing in four-dimensional 'space-time'. According to some theories, this isn't just an abstract frame of reference containing physical objects like stars and galaxies, but a physical substance in itself, analogous to an ocean of water. Just as water is made up of countless molecules, so space-time – according to this theory – is made up of microscopic particles on a deeper level of reality than our instruments can reach.

The theory visualises space-time as a 'superfluid', having zero viscosity. An odd property of such fluids is that they can't be made to rotate in a wholesale fashion, like an ordinary liquid does when you stir it. They break up into tiny vortices – which in the case of superfluid space-time, may be the seeds from which galaxies form.

HOW TO
SPA

Words by **Jonathan O'Callaghan**

O FLY A CRAFT

GET YOUR HANDS ON THE CONTROLS AS WE FIND OUT WHAT SPACE FLIGHT IS LIKE

Humans have been flying into space since 1961. Back then, Soviet cosmonaut Yuri Gagarin was launched on a short trip into space lasting just 108 minutes in an automated spacecraft called Vostok 1. Unsure how humans would cope with the rigours of spaceflight, engineers designed the spacecraft to need no human input – Gagarin was simply a passenger from launch to landing.

But in the subsequent years, things started to change. Complicated manoeuvres in orbit, such as attempting to dock two spacecraft, required direct human input. Similarly, missions to the Moon required real-time input from human pilots to actually land on the surface. It wasn't

© NASA

The crew of Columbia's first mission in its flight deck

until 1981 with the arrival of NASA's Space Shuttle, however, that astronauts would get a real taste of what it's like to pilot a spacecraft fully from post-launch to landing.

Spaceflight is tricky because in the absence of gravity, there are multiple factors to consider. Planes rely on three axes: roll (front to back), pitch (side to side) and yaw (the vertical axis). But in space, with no atmosphere or gravity to also control the vehicle, pilots must also contend with the rotation and orientation of the spacecraft.

Spacecraft are equipped with thrusters to manoeuvre themselves in space. But once they reach orbit, it's not simply a case of pointing where you want to go and flying in that direction. Instead, it's all about orbital mechanics; if you want to catch something ahead of you, you actually need to lower the altitude of your orbit. This makes your orbit around Earth smaller, so you catch up. If you tried to go forwards, your orbit would increase and you would shoot past the target.

Vehicles like the Space Shuttle, which was retired in 2011, relied heavily on human input. With a cockpit that didn't look too dissimilar to that of an aircraft, the pilot used a joystick to manoeuvre the spacecraft in space. Firing different thrusters enabled the orientation of the Shuttle to be changed, letting it perform a number of tasks in orbit such as fixing the Hubble Space Telescope or deploying satellites.

At the end of its mission, the Shuttle would re-enter Earth's atmosphere. Most other spacecraft have handled end-of-mission by returning to Earth via parachute, touching down either on land or at sea, but not the Space Shuttle. Designed to fly through Earth's skies like an extremely heavy glider, the Space Shuttle could be piloted – with some difficulty – to a runway landing on the ground, ready for another flight.

NASA's newest astronauts after graduation, having completed a two-year training programme

There have been a lot of famous astronauts who have piloted different spacecraft. Neil Armstrong, of course, famously piloted the Apollo 11 lunar lander for its historic touchdown on the Moon in July 1969. Running low on fuel and frantically looking for a suitable landing site, Armstrong relied on his expertise to bring himself and Buzz Aldrin to a safe landing, with just seconds of fuel to spare.

Astronaut Robert Crippen, meanwhile, was entrusted with piloting the first crewed Space Shuttle mission in April 1981, carrying just himself and his commander John Young aboard Space Shuttle Columbia.

Today, many spacecraft rely on automation rather than human intervention. Russia's Soyuz spacecraft relies on an automated system to dock with the International Space Station (ISS). SpaceX's upcoming Crew Dragon capsule is designed to be fully autonomous, with astronauts on board having little input. Similarly, Boeing's Starliner spacecraft also uses automation, but with the potential for astronauts to take over when needed.

What do you need to be a space pilot?

A degree

You'll need a bachelor's degree in engineering, biological science, physical science, computer science or mathematics to consider becoming an astronaut.

Flight time

If you want to be a pilot you'll also need at least 1,000 hours of piloting time on jet aircraft.

Good eyesight

You'll need to have 20/20 vision in both eyes if you want to become an astronaut – but you can use glasses!

Leadership skills

Make sure you can demonstrate key leadership skills, which is an important trait for anyone who wants to be an astronaut.

Team player

And you'll need to be able to work as a team – spaceflight is all about working with your crew, and if you can't work together, you won't fly.

Virgin Galactic's space plane is designed to take paying customers to space

Flying a space passenger jet

Over the years, several attempts have been made to build vehicles that combine the flight of a plane with the spacefaring capabilities of a spacecraft, known as space planes. Today the only operational space plane capable of reaching space is Virgin Galactic's SpaceShipTwo. Carried into the air on a modified Boeing jet, the vehicle is then dropped and activates its rocket engine, soaring upwards.

The vehicle is designed to surpass the official boundary of space at 100 kilometres (62 miles) above Earth, where it gives its occupants several minutes of weightlessness. It then falls back into the atmosphere, turning its tail upwards using a 'feathering' system to survive the journey back to Earth and then landing on a runway. It is designed to carry up to eight people on board: two crew and six customers who have paid for the experience of going to space, with ticket prices currently about $250,000 (approximately £190,000).

Astronauts train in diving gear, as being underwater mimics weightlessness

© Bill Brassard/NASA

"In the absence of gravity, there are multiple factors to consider"

Neil Armstrong and Buzz Aldrin spent over 21 hours on the lunar surface

© NASA

STS-1, the first crewed Space Shuttle mission, lifted off on 12 April 1981

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Q&A Interplanetary missions

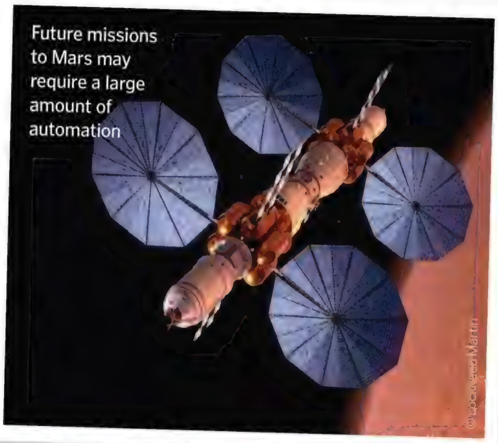
Andrea Accomazzo, head of the Solar System and Exploration Missions Division at the European Space Agency, tells us what it's like to guide uncrewed spacecraft to other worlds


© ESA

What spacecraft have you been involved with?
I've done Venus Express, a probe that flew to Venus. More recently I've been involved in an Earth observation satellite, Sentinel-3A. And now I've been acting as the flight director for the BepiColombo mission to Mercury, and we're launching a probe called Solar Orbiter, which will be orbiting the Sun.

What are the main things that need to be considered when flying to other worlds?
One huge difference is that the orbital mechanics are much more demanding than an Earth-bound mission. The second one is the reaction time; everything on a plane happens much more quickly than on a spacecraft. We collect all the input of what we want to do, we [create] a simulation of what is going to happen, we double check it, then we generate the telecommands for the spacecraft and we uplink them. They're typically valid for the next two or three days or the next week, depending on the mission. This is the way you control the spacecraft.

How do modern spacecraft compare to older spacecraft?
Almost every spacecraft now has an autonomous capability to determine which direction it's oriented in space. For Earth-observation spacecraft we not only have that, but the spacecraft are autonomous in determining where they are positioned around Earth [using GPS]. This is true for spacecraft which are orbiting Earth, but is not the case for interplanetary missions. If I'm approaching Mars, I cannot have a GPS telling me where the spacecraft is with respect to Mars. But I can have a camera that can take pictures of Mars and determines the movement of the spacecraft, and autonomously could determine the relative trajectory of the spacecraft with respect to the body. This is something that might [be used] more and more for spacecraft.


Future missions to Mars may require a large amount of automation

5 FACTS ABOUT SPACEFLIGHT

1 One orbit
Yuri Gagarin's first flight to space in 1961 involved just one orbit of our planet before he returned to Earth's surface in his Vostok 1 spacecraft.

2 Weak at the knees
Prolonged spaceflight can have detrimental effects on the human body, lowering bone and muscle mass, so astronauts can struggle to stand when they return home.

3 Longest flight
The longest time spent by someone on one mission was Russian Valeri Polyakov, who stayed in space for 437 days on the Mir space station from 1994 to 1995.

4 Highest speed
The highest speed ever reached by humans was by the crew of Apollo 10. Their capsule reached 39,897 kilometres per hour on their return from the Moon.

5 Farthest from Earth
The Voyager 1 spacecraft is the farthest from Earth. At about 150 times the Earth-Sun distance, it takes more than 40 hours to send a command and get a response.

"Almost every spacecraft now has an autonomous capability"

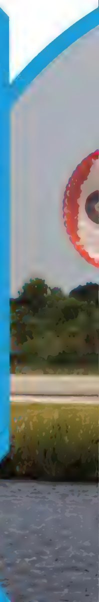

NASA's Curiosity rover was lowered to the surface of Mars autonomously by a 'sky crane'

Timing is everything

When it comes to autonomously landing on or flying to other worlds, the timing of everything in the mission is critical. Spacecraft must be given a series of commands to perform at given times so that they enter orbit around a planet or land on its surface. Sometimes this works, and sometimes it doesn't.

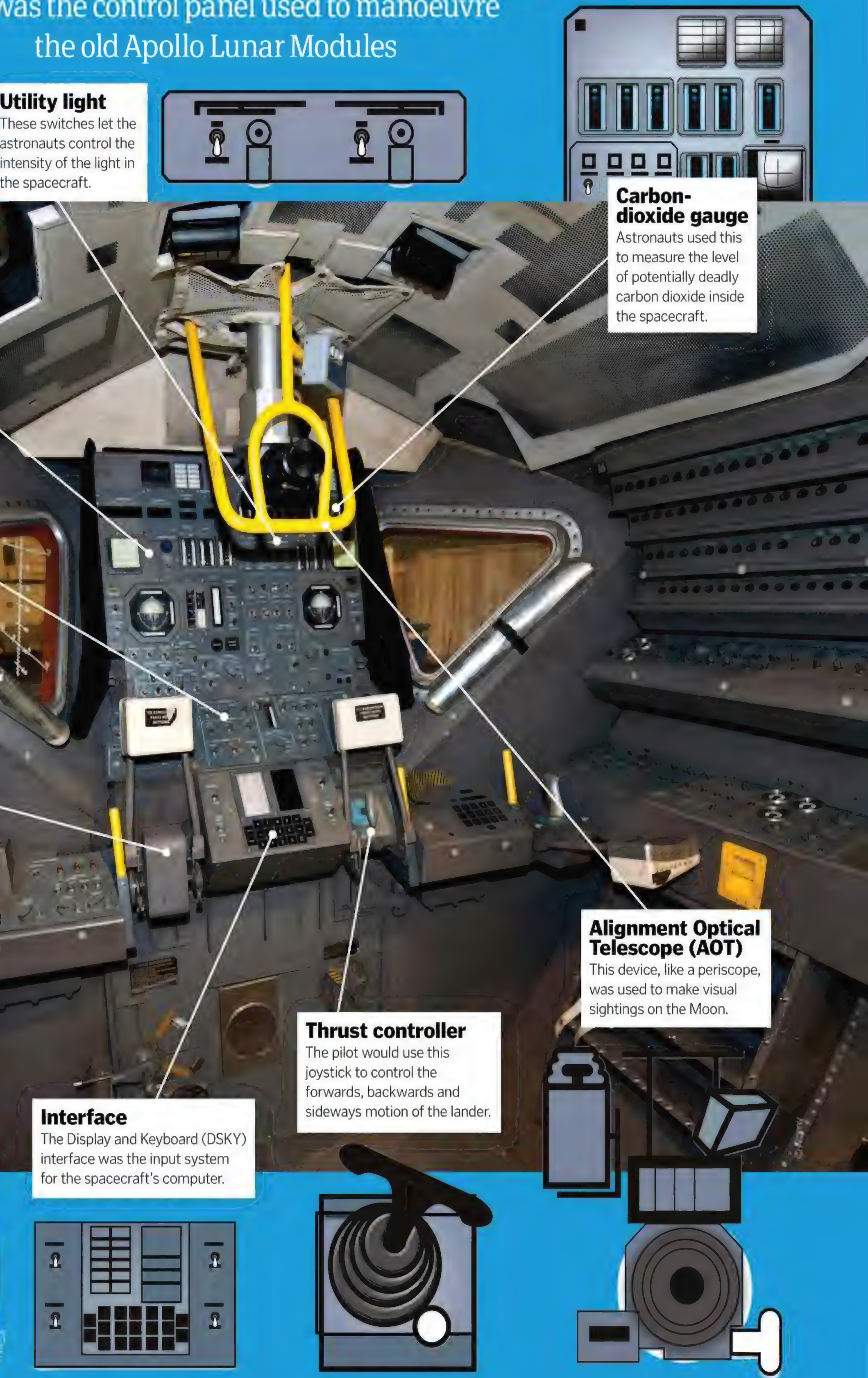
An infamous example of this not quite working was in 2016, when the ESA's Schiaparelli lander experienced a problem landing on Mars. It incorrectly calculated that it was below the surface – when it was still high above the ground – and deployed its parachute too early, leading to a crash landing.

But things can go right, too. Perhaps one of the most complex autonomous manoeuvres on another world was NASA's landing of its Curiosity rover on Mars in 2012. The rover was dropped onto Mars by an innovative 'sky crane' system, with a thruster-powered platform using cables to gently lower the rover onto the surface.



HANDS-ON THE CONTROLS

This was the control panel used to manoeuvre the old Apollo Lunar Modules



Contact lights
This told the crew when they were close to the Moon's surface so they could switch off the engine.

Utility light
These switches let the astronauts control the intensity of the light in the spacecraft.

Carbon-dioxide gauge
Astronauts used this to measure the level of potentially deadly carbon dioxide inside the spacecraft.

Engine circuit breaker
This was used to arm the Ascent Propulsion System on the spacecraft to leave the Moon's surface.

Attitude controllers
This was used to change the angle and orientation of the spacecraft.

Alignment Optical Telescope (AOT)
This device, like a periscope, was used to make visual sightings on the Moon.

Thrust controller
The pilot would use this joystick to control the forwards, backwards and sideways motion of the lander.

Interface
The Display and Keyboard (DSKY) interface was the input system for the spacecraft's computer.

The Space Shuttle could be brought back for a glided touchdown on a runway

HUMAN HABITATS ON MARS

To survive on Mars, we'll need something to live in. Could these homes be the answer?

Words by **Jonathan O'Callaghan**

For decades, sending humans to Mars has been one of the main goals of our space exploration endeavours. Countries like the US and China, and companies such as SpaceX have all expressed a desire to colonise the Red Planet. But to do so, we will also need a way for humans to survive – and thrive – on the surface of this hostile world. And efforts have been long underway to do just that, by designing habitats that humans may live in.

Building a habitat on Mars poses particular challenges that are not faced anywhere on Earth. First there is the lack of pressure – about one per cent of Earth's at sea level – which means habitats must be pressurised. There are also vast temperature swings, from 20 degrees Celsius to as low as -153 degrees Celsius as day turns to night and the Sun's heat escapes through the thin atmosphere. A lack of obvious resources like building materials and water also poses a significant challenge, as does coping with less sunlight – about 44 per cent less than we experience here on Earth.

Entertainment will be important on Mars to stop the astronauts from getting bored

To overcome some of these challenges, NASA has been running the 3D-Printed Habitat Challenge since 2015, to see if anyone can come up with viable solutions to these problems. 3D-printing is deemed to be one of the best ways to build habitats on Mars, reducing the amount of mass that will need to be carried to the surface – especially if we can use Martian resources to print them.

In May 2019, two teams were awarded a combined $700,000 (around £580,000) to further develop the ideas they had suggested – one from New York-based AI SpaceFactory, called MARSHA, and another, Den@Mars, developed by Pennsylvania State University. Both make use of a curved structure in order to reduce the pressures on the habitat while on Mars. But while Den@Mars is a more traditional dome, MARSHA is a cylindrical shape – one of the factors that earned it the top prize from NASA of $500,000 (around £415,000), after successfully printing a one-third scale model of the design in 30 hours almost completely autonomously.

NASA hopes that these designs, or some variant of them, may form the basis of eventual Mars habitats when humans land there at some point in the 2030s or later. Many challenges remain, however, not least working out how to actually land the equipment on Mars that could print these structures, and ultimately sending humans there too. But if some of these challenges can be overcome in the near-term, it raises the prospect of eventual missions in the future.

The walls of the MARSHA habitat will be layered to block radiation and provide insulation

Mars materials

To build a habitat on Mars, MARSHA will use materials directly from the surface of Mars to reduce the amount of resources that need to be carried from Earth. The habitat will be built using basalt fibre extracted from the Martian rock, combined with a renewable bioplastic called polylactic acid (PLA) that can be processed from plants grown on Mars.

The resulting material has a similar strength to carbon fibre yet is much easier to make, while the plastic is a great shield against cosmic radiation. Using PLA also ensures the material is recyclable, and it will not expand and contract too much as temperatures on Mars change. The idea is that a machine on Mars, like a large crane, will be able to use this material to autonomously produce the habitats for astronauts to live inside, once the resources have been produced on the surface.

MARSHA habitats can be built on Mars to house many astronauts

"Building a habitat on Mars poses particular challenges"

The interior of the habitats will be fairly open and bright, promoting the astronauts' circadian rhythms

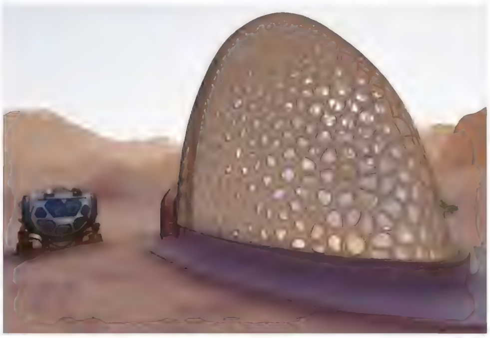
© AI SpaceFactory

Martian houses

Here are some of the other designs in NASA's Mars habitat competition that were considered

Team Kahn-Yates

This team from Jackson, Mississippi, designed a Martian habitat with a mottled design, that can cope with dust storms and the harsh climate on Mars.



© Team Kahn-Yates

Den@Mars

This idea from Pennsylvania State University planned to use digital scanning and a nozzle to squirt out a paste-like substance to produce a dome-shaped structure.

© Den@Mars

5 FACTS ABOUT LIVING ON THE RED PLANET

1 Lower gravity
Mars has just 38 per cent of Earth's gravity, so astronauts on Mars will need to exercise regularly to overcome any loss in bone density and muscle mass.

2 Space radiation
The thinner atmosphere of Mars means that astronauts will be exposed to much more solar and cosmic radiation, and must remain protected on the surface.

3 Launch windows
Owing to the orbits of Earth and Mars, missions between the two can only be launched every 26 months, and it will take about eight months to make the journey.

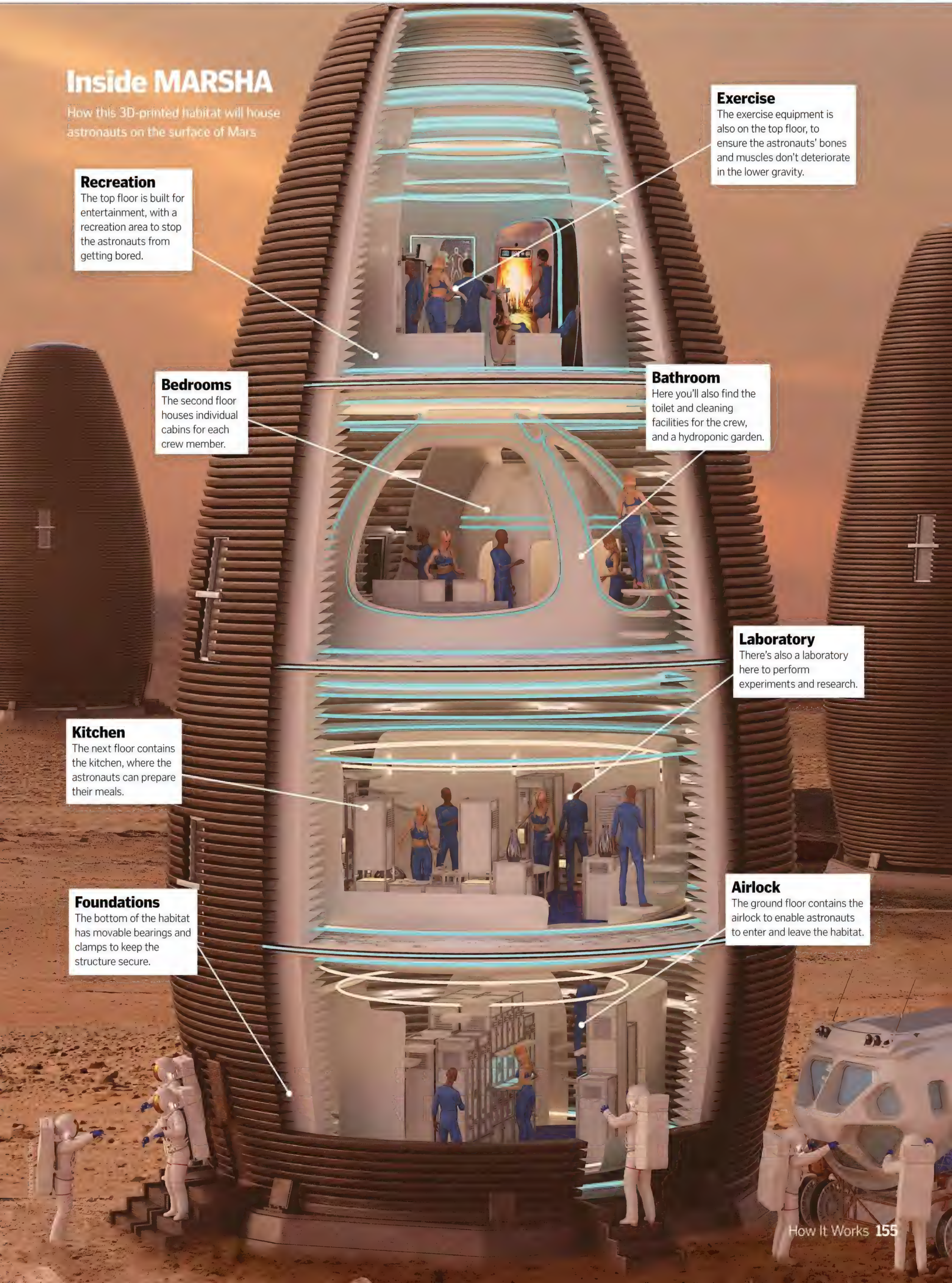
4 Martian water
Water cannot exist as a liquid on Mars because of the low pressure. But it's thought to be frozen under the surface as ice, which could be used by astronauts.

5 Life on Mars?
It's possible that Mars could play host to some form of microbial life. And perhaps it will take astronauts going there for us to find out for sure.

Team SEArch+/Apis Cor

The swooping design for this idea uses the soil of Mars to protect astronauts inside from deadly radiation.

© SpaceX


Inside MARSHA
How this 3D-printed habitat will house astronauts on the surface of Mars
Recreation
The top floor is built for entertainment, with a recreation area to stop the astronauts from getting bored.
Exercise
The exercise equipment is also on the top floor, to ensure the astronauts' bones and muscles don't deteriorate in the lower gravity.
Bedrooms
The second floor houses individual cabins for each crew member.
Bathroom
Here you'll also find the toilet and cleaning facilities for the crew, and a hydroponic garden.
Laboratory
There's also a laboratory here to perform experiments and research.
Kitchen
The next floor contains the kitchen, where the astronauts can prepare their meals.
Foundations
The bottom of the habitat has movable bearings and clamps to keep the structure secure.
Airlock
The ground floor contains the airlock to enable astronauts to enter and leave the habitat.

ALIEN EVOLUTION

Life could arise from a variety of circumstances, but it all depends on what the host planet can offer

Words by **Lee Cavendish**

Alien life is something that everyone ponders at some point. It has allowed science fiction writers and film makers a creative licence, with actors and actresses dressed up in some very questionable attire. However, the truth is that there are so many variables when it comes to creating life, no one can say what alien organisms will look like. All that scientists can do is explore the possibilities.

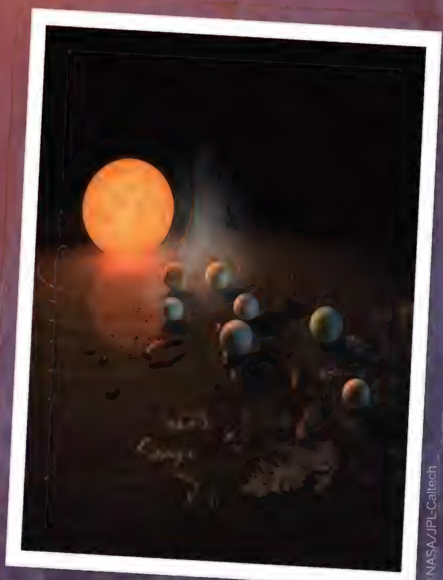
A lot happened over 3.5 billion years for life to evolve on Earth, and it has all stemmed from the chemistry on this planet. The biochemistry of life here is based on carbon, with a water-based medium in our cells creating energy by metabolising oxygen. That is a simple way of describing the chemistry of life on our planet, and this is only the case because Earth has been gifted with this chemistry at a reasonable distance from the Sun. Over the last couple of decades, astronomers have found thousands of planets in different solar systems – known as exoplanets – that exist in a variety of conditions. So should we think that the chemistry of life is the same everywhere? There is definitely a strong argument to say otherwise.

For example, an exoplanet could exhibit life forms based on silicon instead of carbon. Silicon sits below carbon in the periodic table, meaning that it can form the same four bonds with other elements that carbon does. This forms similar long chains of molecules, or polymers. The difference between the two is that silicon has eight more electrons than carbon, which introduces a stronger repulsion factor and therefore makes silicon bonds weaker. The reason why diamonds are one of the strongest materials in the world is because of the way the carbon atoms are arranged.

However, silicon can prevail in more extreme temperatures. For example, silicon-oxygen bonds can withstand temperatures up to about 325 degrees Celsius. Carbon-oxygen bonds would not be able to exist in such conditions. So for exoplanets that orbit closer to their host star, silicon may be the answer.

Then there's the question of water. Earth is within the Sun's habitable zone, a region of space surrounding a star where temperatures are just right for liquid water to exist, which is thought to be vital in supporting life. But what about the exoplanets that aren't so lucky? Well, it doesn't have to be water that can provide a liquid medium in alien cells. Saturn's moon Titan is home to liquid bodies full of complex hydrocarbons methane and ethane. It has an intricate water cycle, similar to that of the Earth, which recycles liquid methane in a location far from the Sun.

Life has a way of adapting and overcoming extreme situations, as there are even signs of life on Earth that exist in the most inhospitable places. For example, in the depths of the ocean, far from the reach of sunlight, tube worms thrive without the need for light. These creatures create energy using the chemical-rich fluid from hydrothermal vents in a process called chemosynthesis. With all these possibilities and all the worlds in the cosmos, alternate alien evolution is entirely plausible.



© NASA/JPL-Caltech

The TRAPPIST-1 star has three planets – e, f and g – orbiting within the star's habitable zone

© Alamy

Earth's most indestructible life form

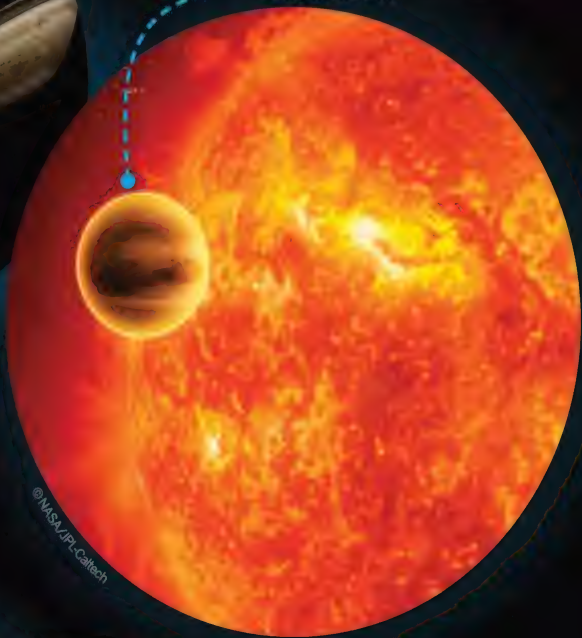
Tardigrades, also known as 'water bears', are eight-legged micro-animals that can thrive against the odds. They can survive just about anywhere, from mountaintops to the bottom of the ocean, and they are also capable of withstanding temperatures from -200 degrees Celsius to over 150 degrees Celsius.

These little creatures have been the subject of much investigation due to their indestructibility – even being launched into space. The results of these tests have shown that they can survive boiling liquids, radiation exposure, extreme pressures, and can be brought back to life after spending years in a dehydrated state; it's thought that only when the Sun dies will the tardigrades cease to exist. Their resilience means that they could also have the capability of existing on different worlds, encouraging the search for life on planets other than Earth.

Tardigrades prefer to live in moist environments like within sediment at the bottom of lakes

ALIEN PLANETS: THE TOP TARGETS

Source: Wikimedia Commons/NuclearVacuum



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Tidally locked worlds

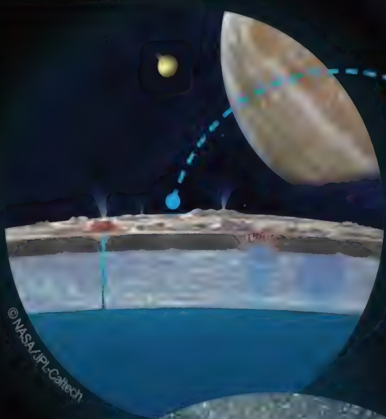
Planets that have one face continuously directed at the host star could circulate heat (provided it has an adequate atmosphere) and create a sweet spot between light and dark with Earth-like conditions.

Example world: 51 Pegasi b, roughly 50 light years away from Earth.

Yo-yo planets

Some exoplanets have extreme fluctuations in their seasons due to an elliptical orbit. The exoplanet could 'yo-yo' between blistering summers and shivering winters, but there could be periods in between where life could prosper.

Example world: 16 Cygni Bb, which is approximately 69 light years from Earth.



© NASA/JPL-Caltech

Ocean worlds

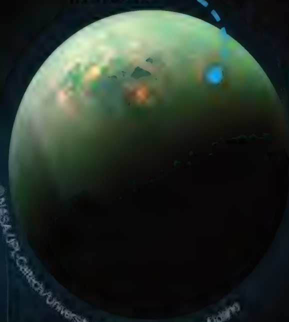
Worlds with an icy surface could have a global ocean underneath that harbours life and gets its energy from ocean floors, as opposed to starlight.

Example world: Jupiter's moon Europa, 35 light minutes away from Earth.

Liquid hydrocarbon worlds

For worlds that exist in colder temperatures than Earth, the same water cycle that was vital for the emergence of life on our world could occur with liquid hydrocarbons, such as methane or ethane.

Example world: Saturn's moon Titan is 1.3 light hours from Earth.



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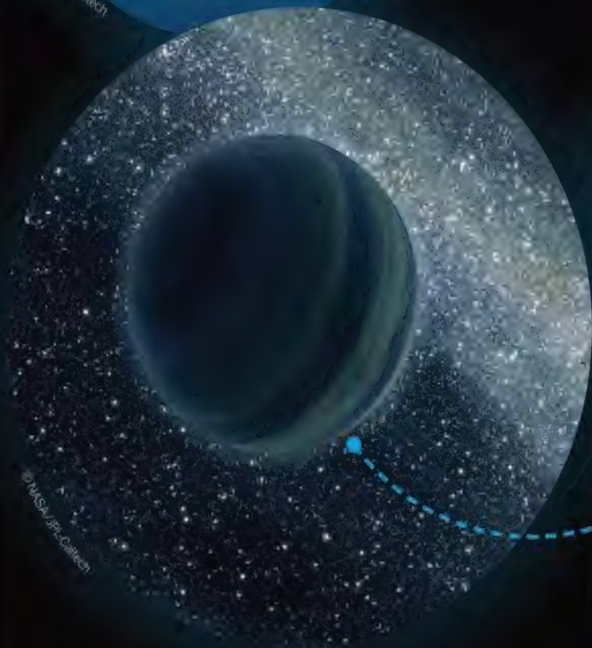

© NASA/JPL-Caltech

Rogue planets

Whether it's due to a collision or stellar explosion, planets can be ejected into deep space. The planet's core could still fuel life while in darkness, much like ocean worlds.

Example world: PSO J318.5-22 does not orbit a parent star, roughly 80 light years away from Earth.

1
Gliding by
An exoplanet that has a thick atmosphere could drive its inhabitants to evolve to fly around, exerting as little force as possible as they glide through the planet's sky.

2
Non-stop flying
If aliens exhibit similar oxygen-transport systems in their bodies to Earth's life forms, a world with more oxygen could mean the creatures there fly non-stop.

3
Fixed wings
If an alien has a fixed-wing structure, with the wings only moving slightly for steering, then less muscle is needed and less energy is exerted when travelling through the sky.

4
The blind side
If a host planet is a rogue world with no host star to orbit and therefore no light, there is no need to see in the constant darkness, and aliens may evolve without eyes.

5
Hardened tusks
Mammals like elephants develop tusks for feeding and self-defence, which could be made bigger and stronger if the alien's host planet is abundant in calcium.

6
Energy source
Without sunlight, organisms need a substitute for photosynthesis; chemosynthesis. They could get energy through reactions with inorganic compounds.

7
A plant-animal hybrid
On other planets, hybrid organisms could find themselves having to relocate to different positions on a set of legs, in order to collect light and hydrate.

8
On the hunt for nutrients
Some alien life could evolve to shift between various locations to suck up the nutrients in a different spot across the planet's surface.

9
Survival of the fittest
If Charles Darwin's contribution to understanding evolution applies on other planets, these half-plant-half-animal creatures could develop a basic camouflage.

The different shapes and sizes of aliens

With the endless possibilities of what life could look like, here are some creative ideas for alien species

Source: Wikimedia Commons

Tube worms are living examples of life forms that don't depend on sunlight to survive

© NASA

NASA's TESS mission will search for exoplanets smaller than Neptune orbiting nearby stars

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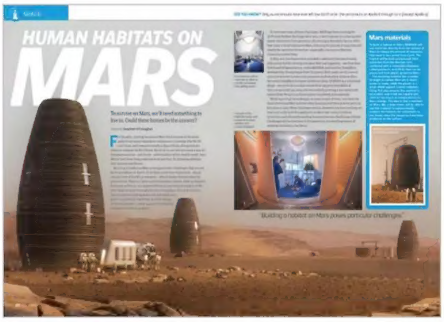

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